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AN ANALYSIS OF LINE-OF-SIGHT HF RADAR
OBSERVATIONS FOR THE SA-5 AND SA-6 LAUNCHES
AND SOME COMPARISONS WITH VHF TELEMETRY
MEASUREMENTS

(TITLE: SECRET)

RADAR AND TELEMETRY OBSERVATIONS
FOR TWO SATURN LAUNCH VEHICLES

(TITLE: UNCLASSIFIED)

This report is the SIXTY-FIFTH of a series of CHAPEL BELL reports (formerly TEPEE reports) made under Contract Nonr-4204(00) under the joint sponsorship of the Office of Naval Research and the Advanced Research Projects Agency (ARPA Order 32)

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FOR TWO SATURN LAUNCH VEHICLES

(TITLE: UNCLASSIFIED)

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TABLE OF CONTENTS

Section		Page
1.	<u>INTRODUCTION</u>	1-1
2.	<u>DATA AND DISCUSSION</u>	2-1
2.1.	THE SA-5 FLIGHT	2-1
2.1.1.	<u>VHF Telemetry from the SA-5 Vehicle</u>	2-1
2.1.2.	<u>Signatures Observed with HF Polystatic Direct-Lock Radars</u>	2-4
2.1.2.1.	Cape Kennedy Receiving Brunswick	2-4
2.1.2.2.	San Salvador Receiving Brunswick	2-8
2.1.2.3.	Brunswick Receiving San Salvador	2-14
2.1.2.4.	Cape Kennedy Receiving San Salvador	2-20
2.1.2.5.	Brunswick Monostatic	2-24
2.2.	THE SA-6 FLIGHT	2-24
2.2.1.	<u>VHF Telemetry from the SA-6 Vehicle</u>	2-24
2.2.2.	<u>Signatures Observed with HF Polystatic Direct-Lock Radars</u>	2-27
3.	<u>FLAME-ASSOCIATED VHF AND HF PHENOMENA</u>	3-1
4.	<u>CONCLUSIONS</u>	4-1
5.	<u>REFERENCES</u>	5-1

SECRET

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LIST OF FIGURES

Figure		Page
1	Line-of-sight radar locations with respect to SATURN launch azimuth.	1-3
2	SATURN block 2 vehicle, telemetry antenna and retro-rocket locations.	2-2
3	Telemetry signal attenuation due to SA-5 retro-rockets.	2-3
4	AMR test 0169, SATURN SA-5, Cape Kennedy receiving Brunswick, Georgia, operating frequency - 22.7 Mc/s.	2-5
5	Signature cross section, SATURN SA-5, Cape Kennedy receiving Brunswick, Georgia.	2-7
6	Comparison of retro-rocket plume size and VHF telemetry signal strength, SATURN SA-5 vehicle.	2-9
7	Measured VHF telemetry signal strengths, Grand Bahama Island, link. (After Ely, et al., p. 43 of Ref. 4.)	2-10
8	Measured SHF signal strengths, C-band radar, San Salvador. (After Ely, et al., p. 53 of Ref. 4.)	2-11
9	AMR test 0169, SATURN SA-5, San Salvador receiving Brunswick, Georgia, operating frequency - 22.7 Mc/s.	2-12
10	Signature cross section, SATURN SA-5, San Salvador receiving Brunswick, Georgia.	2-13
11	AMR test 0169, SATURN SA-5, Brunswick, Georgia receiving San Salvador, operating frequency - 22.8 Mc/s.	2-15
12	Signature cross section, SATURN SA-5, Brunswick, Georgia receiving San Salvador.	2-16
13	AMR test 0169, SATURN SA-5, Brunswick, Georgia receiving San Salvador, operating frequency - 22.8 Mc/s.	2-18
14	Comparison of calculated and observed doppler-spectrum lines, SATURN SA-5 stages S-I and S-IV, Brunswick, Georgia receiving San Salvador.	2-19

SECRET

SECRET

LIST OF FIGURES (continued)

Figure		Page
15	AMR test 0169, SATURN SA-5, Cape Kennedy receiving San Salvador, operating frequency - 22.8 Mc/s.	2-21
16	AMR test 0169, SATURN SA-5, Cape Kennedy receiving San Salvador, operating frequency - 22.8 Mc/s.	2-22
17	Comparison of calculated and observed doppler-spectrum lines, SATURN SA-5, stages S-I and S-IV, Cape Kennedy receiving San Salvador.	2-23
18	AMR test 0169, SATURN SA-5 signature, liftoff - 1625:01Z, Brunswick, Georgia monostatic radar, 29 January 1964.	2-25
19	Cross section of the Brunswick, Georgia monostatic retro-rocket signature, SATURN SA-5.	2-26
20	Telemetry signal attenuation due to retro-rockets.	2-28
21	AMR test 2769, SATURN SA-6, Cape Kennedy receiving San Salvador, operating frequency - 17.7 Mc/s.	2-29
22	AMR test 2769, SATURN SA-6, MTI record, Cape Kennedy receiving San Salvador, operating frequency - 17.7 Mc/s.	2-31
23	AMR test 2769, SATURN SA-6, doppler spectrum, Cape Kennedy receiving San Salvador, operating frequency - 17.7 Mc/s.	2-32
24	AMR test 2769, SATURN SA-6, doppler spectrum (continued), Cape Kennedy receiving San Salvador.	2-34
25	Comparison of calculated and observed doppler spectrum, SATURN SA-6, stages S-I and S-IV, Cape Kennedy receiving San Salvador.	2-35

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ABSTRACT

The records obtained in line-of-sight, HF radar observations during two SATURN rocket launches (SA-5 and SA-6) are analyzed. The measurements were made as a part of a close-in phenomenology program which covered approximately 60 launches of various types of vehicles from the Air Force Eastern Test Range (AFETR). Results pertaining to other types of vehicles are reported separately.

The line-of-sight observations employed HF pulse transmitters at Brunswick, Georgia and San Salvador Island. Each site received its own transmission monostatically, and the other site's transmissions bistatically. Both transmissions were received bistatically at Cape Kennedy, Florida.

The pulse amplitude data have been analyzed to obtain the radar cross sections, which are presented as functions of time. The variation of these cross sections with additional parameters, such as altitude, aspect angle, and bistatic angle, are discussed. The results are also compared with information recently released concerning rocket-exhaust effects upon VHF telemetry transmissions during the two launches of interest. A time-correlation of VHF attenuation events with increases in HF radar cross section is noted, especially at first-stage retro-rocket ignition.

Selected portions of the HF radar data have been analyzed as pulse-doppler data to obtain the doppler spectra. When the vehicle is above 100 kilometers (km) in altitude, the doppler spectrum suffers substantial spreading, which in some cases completely filled the 50-c/s folded spectrum of the pulse-doppler radars. Similarly, the VHF telemetry signals exhibited spectral spreading, up to a maximum of 1000 c/s.

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1. INTRODUCTION

A series of 'close-in' missile-launch-phenomenology experiments at the Air Force Eastern Test Range (AFETR) were conducted by various organizations under sponsorship of the Advanced Research Projects Agency (ARPA) and the Office of Naval Research (ONR) during early 1964. As part of this program, the Electro-Physics Laboratories (EPL) operated direct-look (line-of-sight) HF radars against most missile and space vehicle launches.

Among the launches probed by HF radars were AFETR test 0169 and test 2769, the SATURN SA-5 and SA-6 vehicles, respectively. Launch-phase signatures were obtained at HF with a variety of monostatic and bistatic radar-path geometries. Figure 1 shows the geographic layout of the close-in sites used for the POLYSTATIC radar operations, and Table 1 shows the radar configurations and antennas used for the SA-5 and SA-6 tests.

Three transmitters were used during the POLYSTATIC experiments: (1) a 300-kw peak-power transmitter located "over-the-horizon" at Muirkirk, Maryland; (2) a 5-kw peak-power transmitter at Brunswick, Georgia; and (3) a 5-kw peak-power transmitter at San Salvador Island. The Brunswick and San Salvador transmitters operated at 100 pulses/second with a 400-microsecond pulse width, while the Muirkirk transmitter operated at 20 pulses/second with a 1-millisecond pulse width. A complete review of the line-of-sight radar systems may be found in Ref. 1, and the primary goals of the POLYSTATIC experiments are detailed in Ref. 2.

Stated briefly, the goal of the POLYSTATIC program was an experimental exposition of the size and nature of the HF radar target evoked during the powered phase of a variety of liquid-propelled and solid-propelled rockets. The ultimate purpose of such an exposition is, of course, to furnish the detailed knowledge of the target properties

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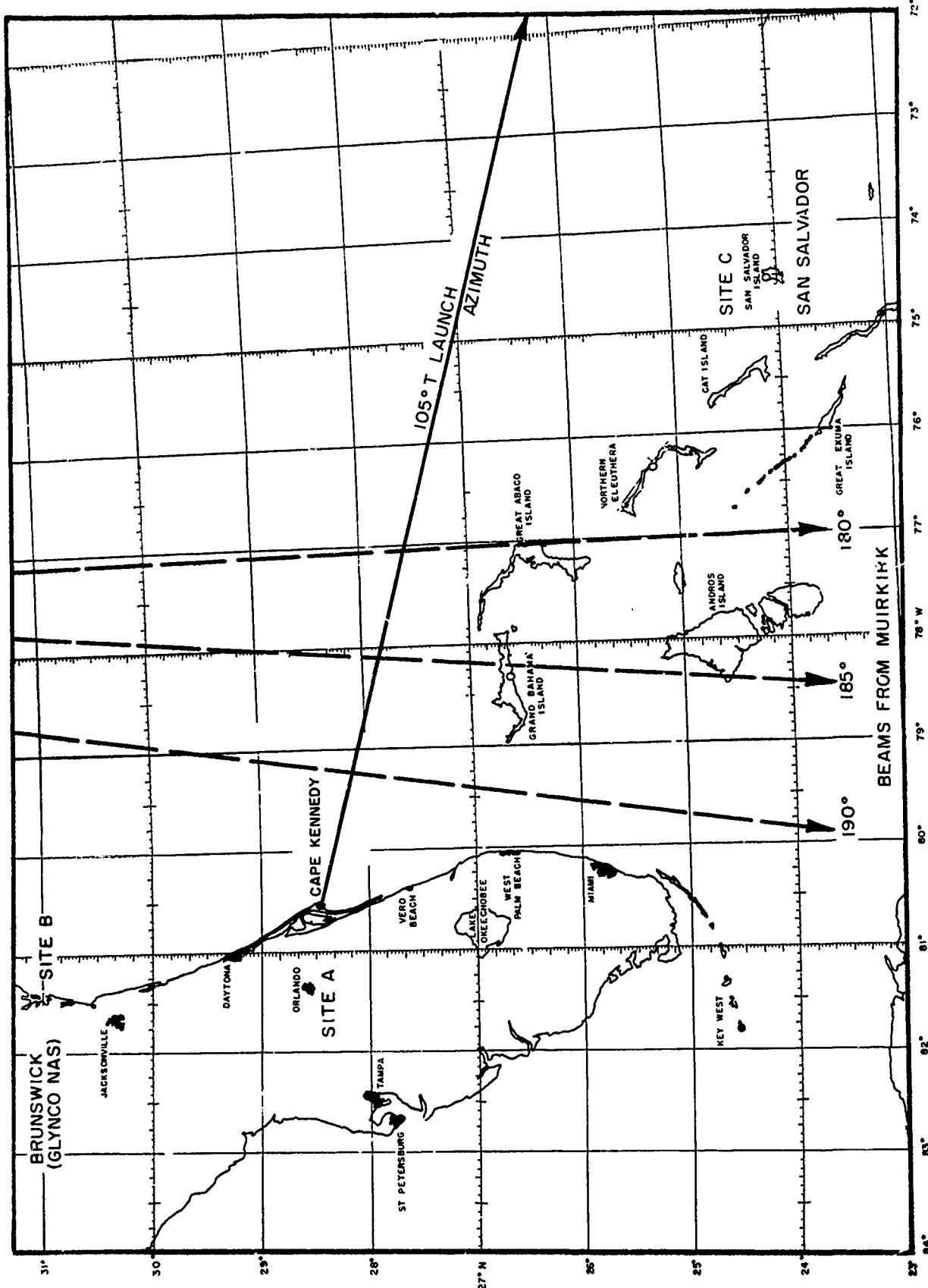
required by a system designer attempting to optimize the design of an OHD radar system.

The nature and properties of the HF radar target are complicated functions of a number of basic parameters, including: time after liftoff; altitude and ambient atmospheric conditions; radar frequency; aspect angle, and (where applicable) bistatic angles; rocket-burn program; rocket type; etc. The range of variability of the parameters may be reduced (as in the present case) by treating, as a group, the tests made for a particular type of vehicle. The effects of the remaining parameters are more difficult to isolate; the effort to do so forms a major part of the analysis, as discussed in the following pages.

An unusual feature of the tests discussed in this report is the availability of supporting data taken in the VHF portion of the spectrum. Recently, Ely and Hockenberger (Refs. 3, 4 and 5) have presented data on the SA-5 and SA-6 flights concerning the effects of rocket exhaust on VHF telemetry and SHF radar performance, which may be directly correlated with some of the signature features observed at HF.

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Figure 1. Line-of-sight radar locations with respect to
SATURN launch azimuth.

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Table 1. Summary of the radar configurations and antennas used for the SA-5 and SA-6 tests.

<u>Radar Configuration</u>	Test 0169		Test 2769	
	<u>Transmit Antenna</u>	<u>Receive Antenna</u>	<u>Transmit Antenna</u>	<u>Receive Antenna</u>
Cape Kennedy receiving San Salvador	4-element broadside array*	16-element broadside array*	4-element broadside array*	16-element broadside array*
Cape Kennedy receiving Brunswick	4-element broadside array*	16-element broadside array*	4-element broadside array*	16-element broadside array*
Cape Kennedy receiving Muirkirk	Rhombic antenna	log periodic array	log periodic array	log periodic array
	Rhombic antenna	16-element broadside array*	log periodic array	16-element broadside array*
Brunswick receiving Muirkirk	Rhombic antenna	log periodic array	log periodic array	log periodic array
Brunswick receiving San Salvador	4-element broadside array*	4-element broadside array*	4-element broadside array*	4-element broadside array*
Brunswick receiving Brunswick	4-element broadside array*	4-element broadside array*	4-element broadside array*	4-element broadside array*
San Salvador receiving Brunswick	4-element broadside array*	4-element broadside array*	4-element broadside array*	4-element broadside array*
San Salvador receiving San Salvador	4-element broadside array*	4-element broadside array*	4-element broadside array*	4-element broadside array*

*The individual elements consisted of broadband, vertical monopoles.

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These signature features of the SATURN tests show a complex target associated with the S-I and S-IV stages after separation. A discussion of these features and their origin is presented in this report.

Figures 2, 3, 6 and 20 of this report have been reproduced with the permission of the American Institute of Aeronautics and Astronautics (AIAA). These figures originally appeared in the paper "Rocket Exhaust Effects on Radio Frequency Transmission" (Ref. 3 of this report) given by Olen P. Ely and Robert W. Hockenberger at the AIAA 6th Solid Propellant Rocket Conference in Washington, D. C., February 1-3, 1965.

Figures 7 and 8 are after Olen P. Ely, Robert W. Hockenberger, Parley Howell and Geddes Boone. The original figures, from which Figures 7 and 8 were derived, were presented in NASA Technical Memorandum X-53073 (Ref. 4 of this report).

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2. DATA AND DISCUSSION

2.1. THE SA-5 FLIGHT

The SA-5 SATURN test vehicle was launched from Cape Kennedy on 29 January 1964 on a true azimuth of 105° T, at 1625:01 GMT. The test placed an instrument unit (IU) into a 500-day elliptical orbit. Complete staging and performance monitoring measurements were conducted for the test vehicle by the AFETR range instrumentation and tracking facilities.

2.1.1. VHF Telemetry from the SA-5 Vehicle

The measured signal strength of VHF (225 to 260 Mc/s) telemetry transmissions from the SA-5 vehicle indicated a large decrease in signal strength upon ignition of the first (S-I) stage retro-rockets, as compared to pre-retro-ignition signal levels. Location of the retro-rockets with respect to the telemetry antennas is shown in Figure 2.

The retro-thrusters of the SATURN vehicles are small, solid-fueled Aerojet General Genie rockets, while the S-I main propulsion stage and the S-IV second stage are liquid-fueled. Ely and Hockenberger (Ref. 3) report severe attenuation of telemetry signals (observed at Cape Kennedy during the SA-5 tests), ranging from 50 to 60 db for approximately 3 seconds, as shown in Figure 3. The retro-rockets burned for approximately 2 seconds and were ignited at $T_0 + 147.16$ seconds. The onset of absorption was very rapid, taking approximately 0.1 second after retro-ignition for the signal to be attenuated by 60 db on the 1J transmissions. Recovery of telemetry signal strength after the termination of retro-rocket burning took approximately 1 second. This extremely high absorption was indicative of a highly ionized region in the vicinity of the missile.

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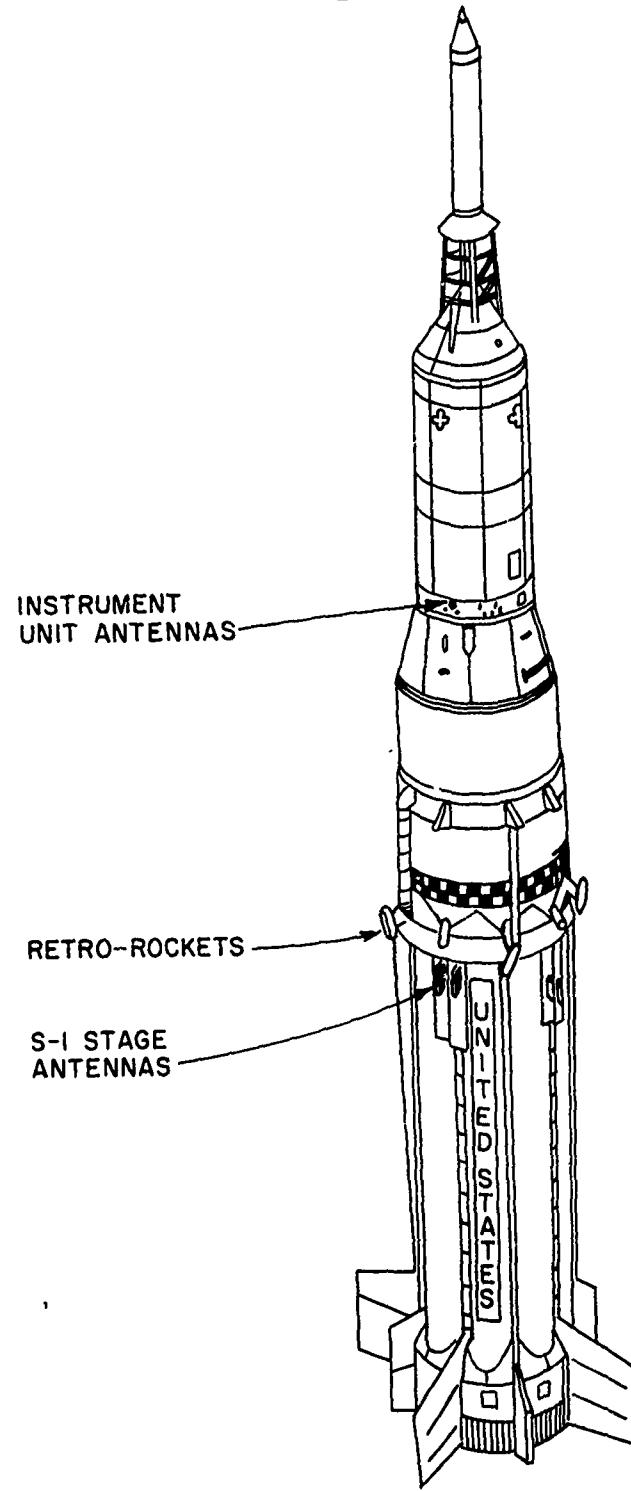


Figure 2. SATURN block 2 vehicle, telemetry antenna and retro-rocket locations.

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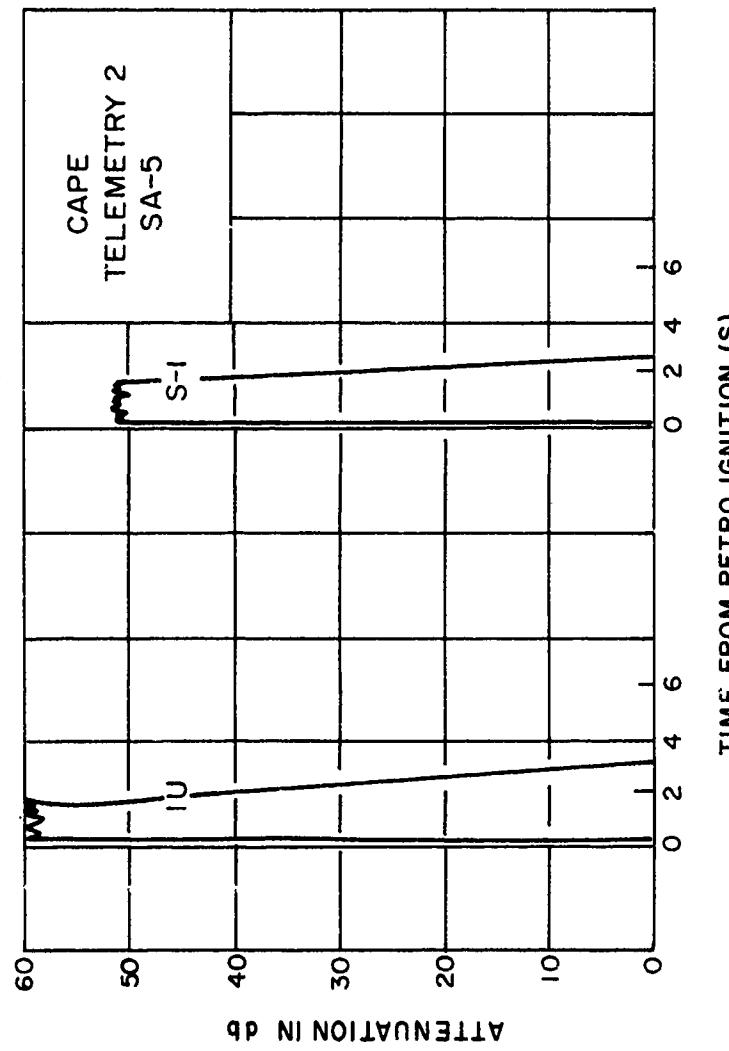


Figure 3. Telemetry signal attenuation due to SA-5 retro-rockets.

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Although some telemetry flame attenuation was observed during both the S-I and S-IV stage propulsion intervals on the Cape telemetry records, these active stages did not produce a total loss of telemetry data. The maximum flame attenuation for the S-I stage was reported as 26 db (Ref. 4, p. 19), while the S-IV stage flame attenuation was considered to have negligible effect on VHF telemetry (Ref. 4, p. 22). The retro-rockets, on the other hand, not only caused a total loss of VHF telemetry at the Cape receiver for several seconds, but also produced a momentary drop of these signals to the receiver threshold at all monitoring sites.

2.1.2. Signatures Observed with HF Polystatic Direct-Look Radars

2.1.2.1. Cape Kennedy Receiving Brunswick

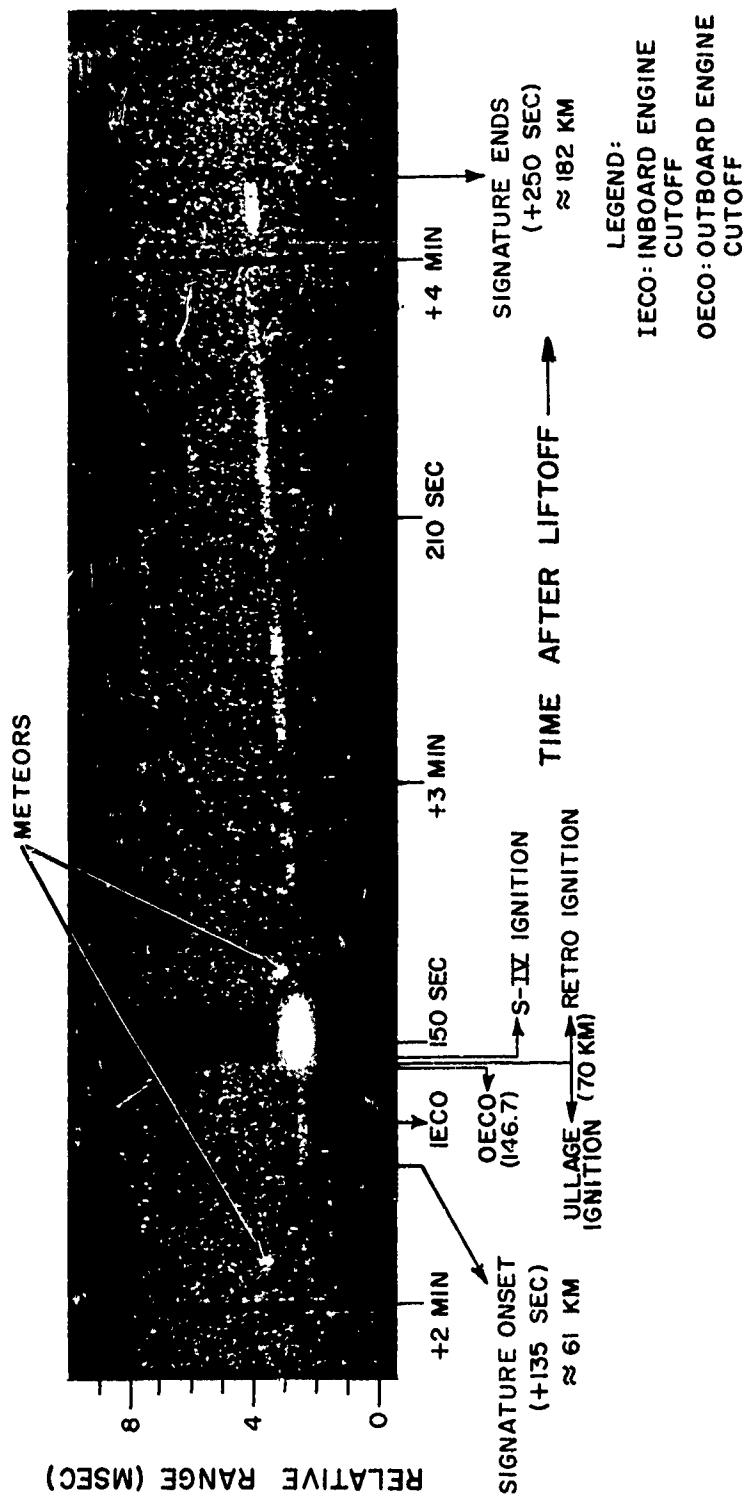
The creation of a local, highly-ionized region by the retro-rockets was verified by the HF radar records to be discussed.

As may be seen in Figure 4, Cape Kennedy's reception of the Brunswick pulse transmissions first displays a missile flame signature from the SA-5 vehicle at $T_0 + 135$ seconds (the missile altitude was approximately 61 km). This signature fades as the S-I stage engines are cut off in the following sequence: inboard engines at $T_0 + 140.75$ seconds, then outboard engines at $T_0 + 146.7$ seconds.

After the ullage rockets and retro-rockets are ignited at $T_0 + 147.2$ seconds, returns are again obtained from the SA-5 rocket at approximately $T_0 + 147.6$ seconds; the amplitude of these echoes becomes very large by $T_0 + 148$ seconds. This specular signature appears for 9 seconds, and its amplitude exhibits the typically high fading rate observed for other missile flame signatures. The HF target is observed approximately 6 seconds longer than the period of high absorption for the VHF telemetry signals from the SA-5 vehicle.

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Figure 4. AMR test 0169, SATURN SA-5, Cape Kennedy receiving Brunswick, Georgia, operating frequency - 22.7 Mc/s.

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At $T_0 + 155$ seconds, the amplitude of returns decreases to the noise level, and the flame signature does not reappear until $T_0 + 167$ seconds when the missile reaches an altitude of 100 km.

The flame signature is observed intermittently from $T_0 + 167$ seconds to $T_0 + 250$ seconds, and a very noticeable increase in signal amplitude is observed at $T_0 + 244$ seconds, just before the signature ends. An inspection of the optical tracking records made of the SA-5 flight indicated that a large amount of fuel and/or oxidizer continued to be ejected from the separated S-I stage in the vicinity of the S-IV stage for at least 10 to 20 seconds after retro-rocket ignition. Since the flame from the powered S-I stage before separation produced a clearly distinguishable signature, of modest cross section, ionization from out-gassing after separation could have enhanced the retro-rocket signature and might also have accounted for the longer duration of the HF signature as compared to the duration of the VHF absorption.

The radar cross sections were calculated by the method described in Ref. 6, using the postflight trajectory data and the scalings of the received signal amplitude. The target-echo power produced by the retro-fire event was approximately 3 orders of magnitude larger than that observed for the burning S-I main stage (Figure 5). Since the S-IV stage does not ignite for nearly 3 seconds after the retro-rockets are started, the formation of this highly ionized region should be attributed to a combination effect of the S-I outgassing/afterburning and the retro-rocket flame, with a negligible contribution from the S-IV stage. The large difference in observed target size between the burning solid and liquid stages might be caused by the higher specific impulse delivered to the ambient ionosphere by the forward-directed retro-rockets.

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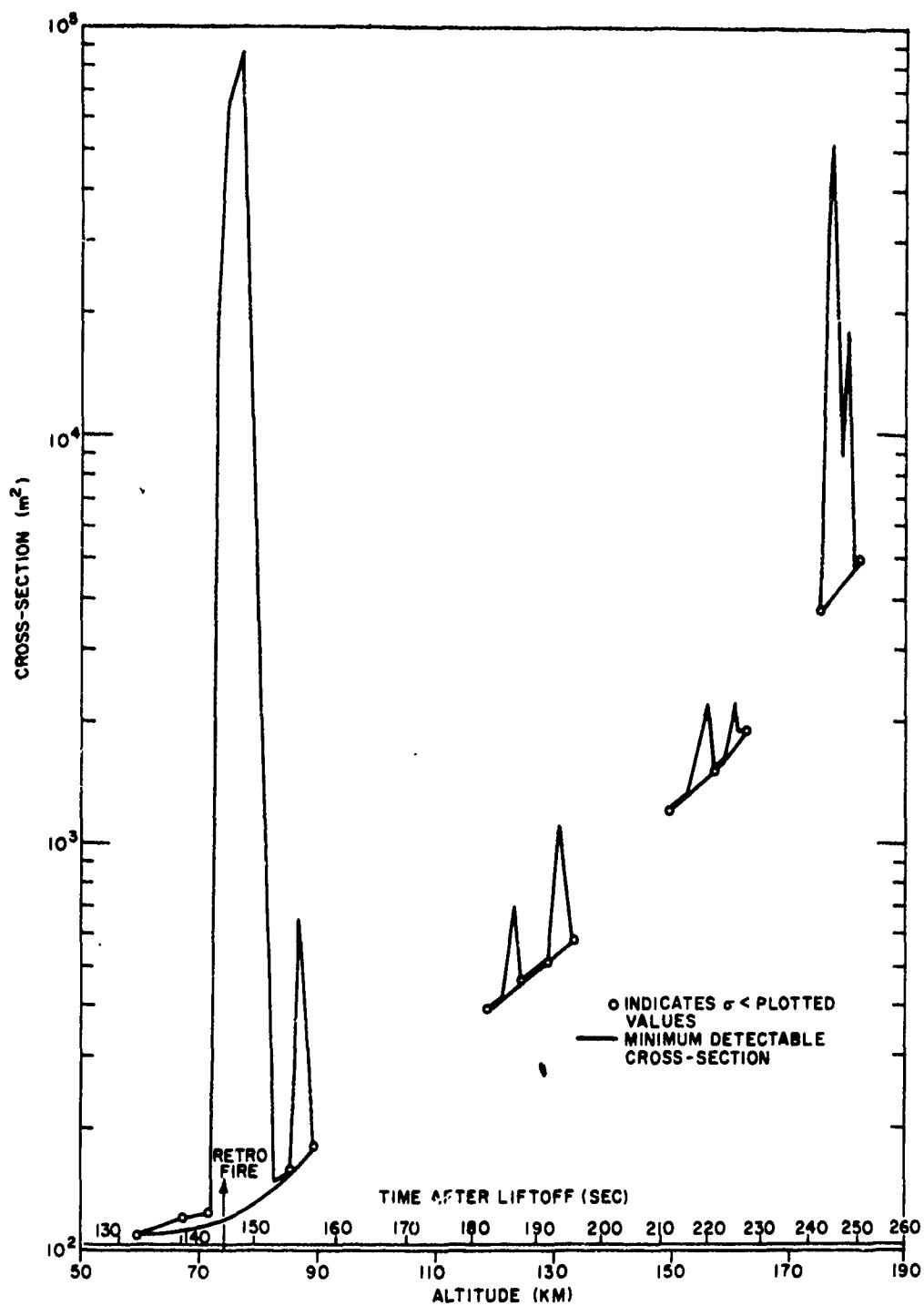


Figure 5. Signature cross section, SATURN SA-5,
Cape Kennedy receiving Brunswick, Georgia.

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From the optical tracking data and characteristics of the tracking telescope, Ely and Hockenberger (Ref. 3) have obtained the approximate time-variation of the optical target diameter, as shown in Figure 6. The relative amplitude of the received telemetry signals and the size of the retro-rocket plume appear to be directly correlated (see Figure 6).

Increased VHF absorption, during another period corresponding to an enhancement of HF signature amplitude, is illustrated further by Figures 4, 5, 7, 8, and 10. The enhanced HF signature at $T_0 + 244$ seconds shown on Figures 4, 5, and 10, occurs at a time of increased absorption (6 to 10 db as seen in Figures 7 and 8) of the VHF telemetry and SHF radar signals observed at Grand Bahama and San Salvador Islands.

2.1.2.2. San Salvador Receiving Brunswick

Figure 9 presents the missile signature obtained from San Salvador reception of the Brunswick transmissions. Before the signature interval, there were moderately strong signals (presumably caused by E_s coupling) at 3 to 4 milliseconds relative range, which tend to mask the onset of the missile signature. The missile signature is recognizable, however, as a drastic increase to the amplitude of radar returns, with some additional echo-pulse spreading. The signature is similar to that obtained from the Cape Kennedy-receiving-Brunswick path except for the much stronger returns appearing in the $T_0 + 2.5$ -minute to $T_0 + 4$ -minute interval, as shown on the San Salvador record.

Retro-rocket ignition again causes a very large increase in echo strength, followed by an interval of weaker returns from the powered S-IV stage, until $T_0 + 164$ seconds when the signature amplitude is again observed to increase. The radar cross section time history of this signature is presented in Figure 10. The cross section was

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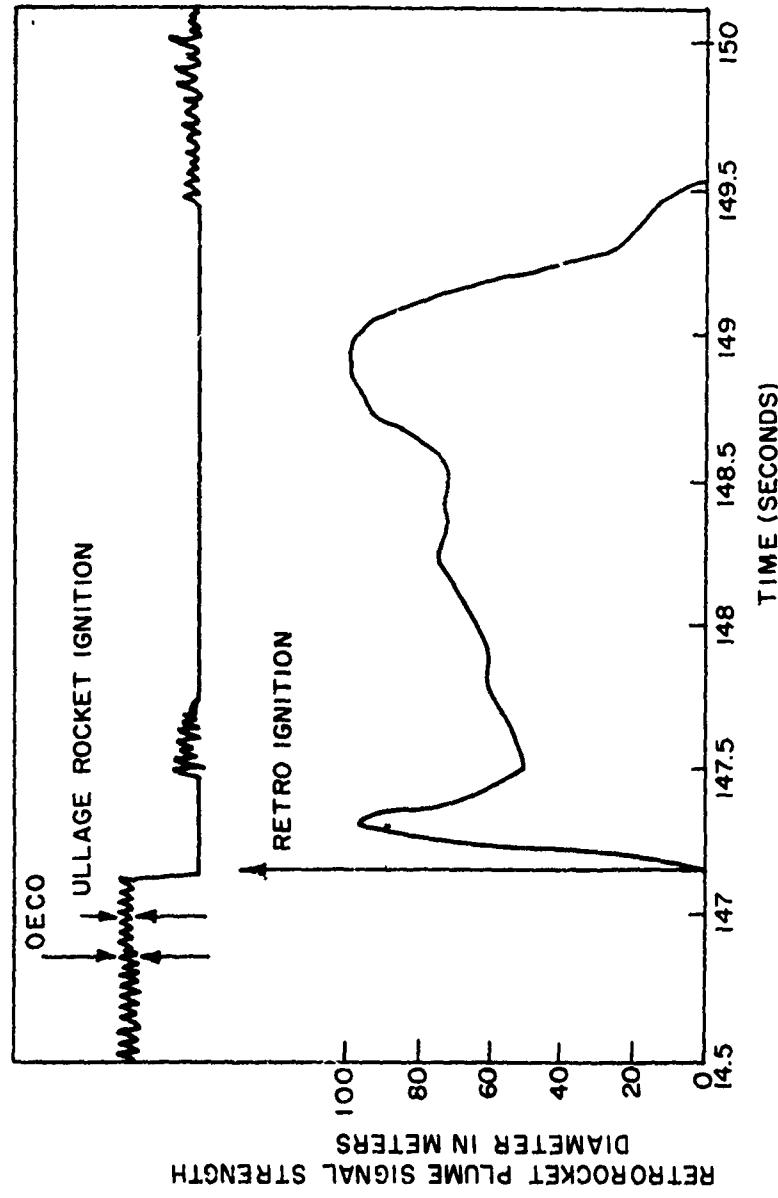


Figure 6. Comparison of retro-rocket plume size and VHF telemetry signal strength, SATURN SA-5 vehicle.

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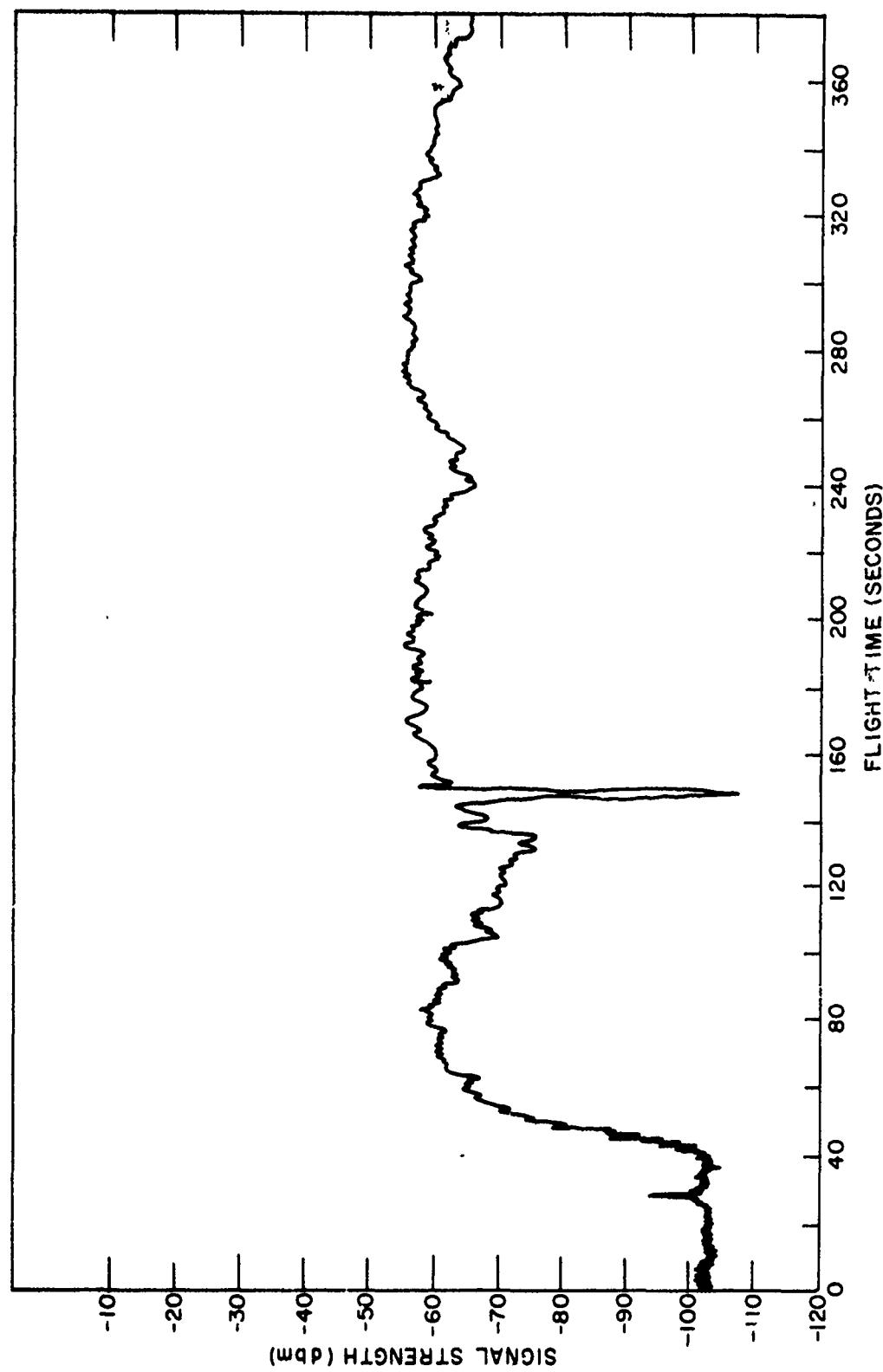


Figure 7. Measured VHF telemetry signal strengths, Grand Bahama Island, link.
(After Ely, et al., p. 43 of Ref. 4.)

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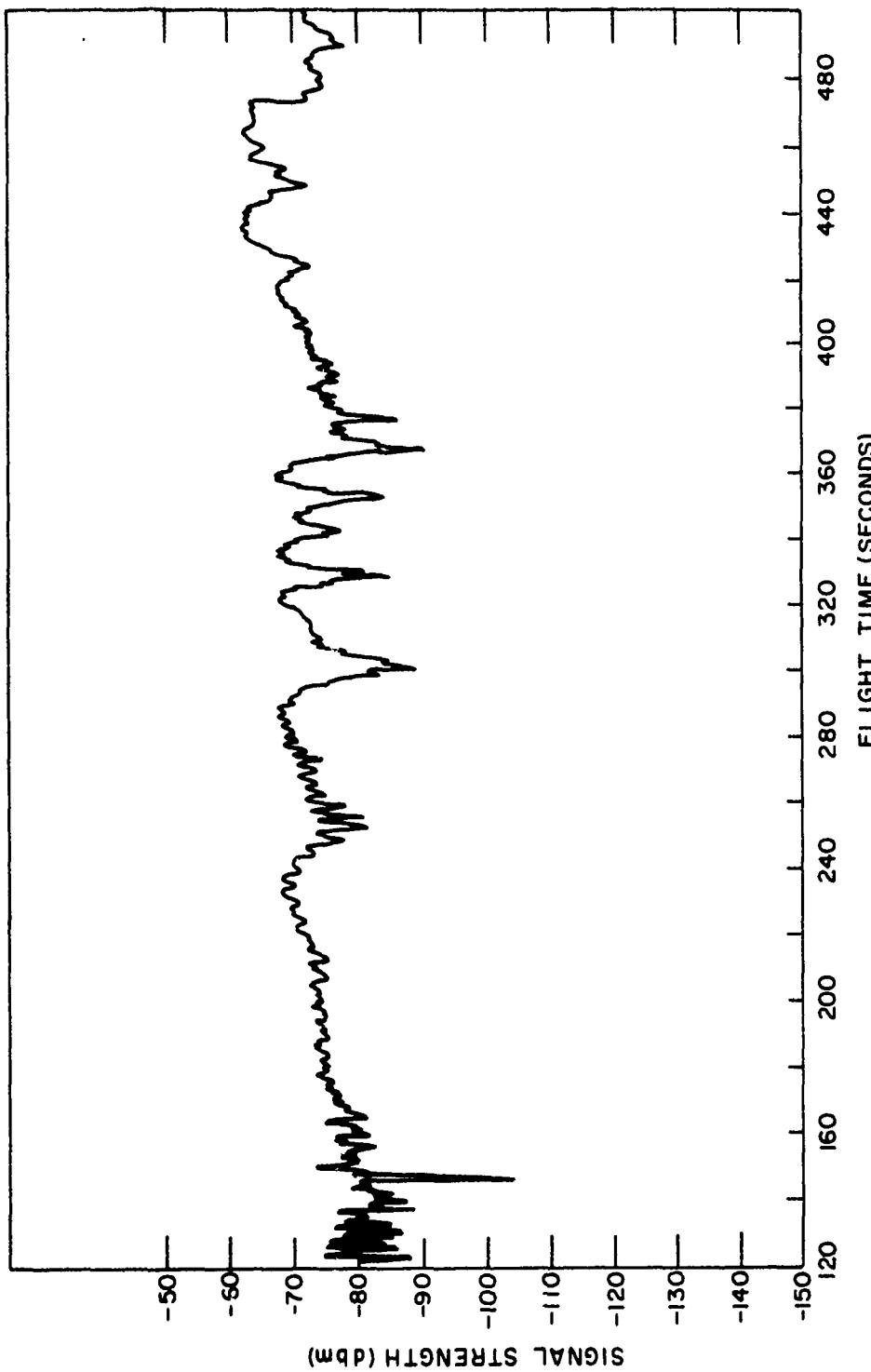
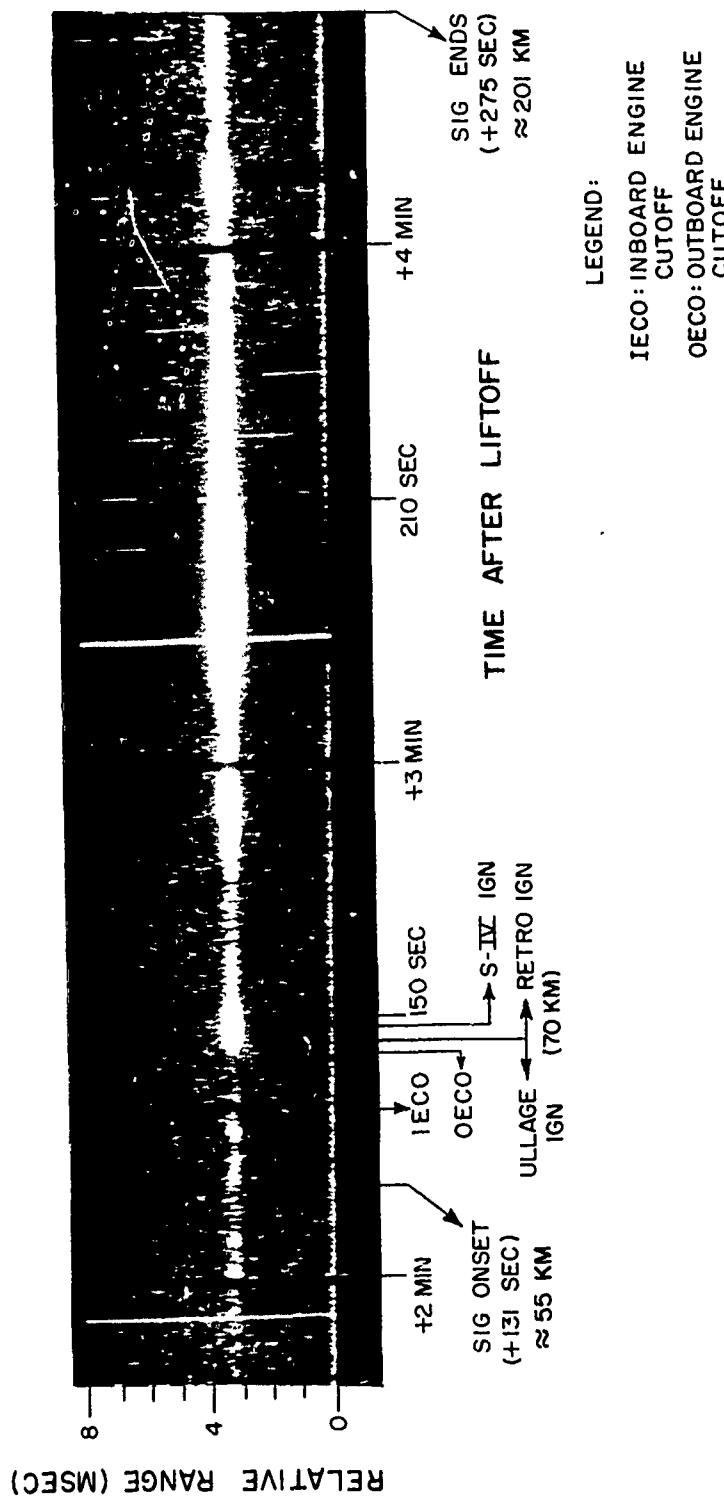


Figure 8. Measured SHF signal strengths, C-band radar, San Salvador.
(After Ely, et al., p. 53 of Ref. 4.)

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Figure 9. AMR test 0169, SATURN SA-5, San Salvador receiving
Brunswick, Georgia, operating frequency - 22.7 Mc/s.

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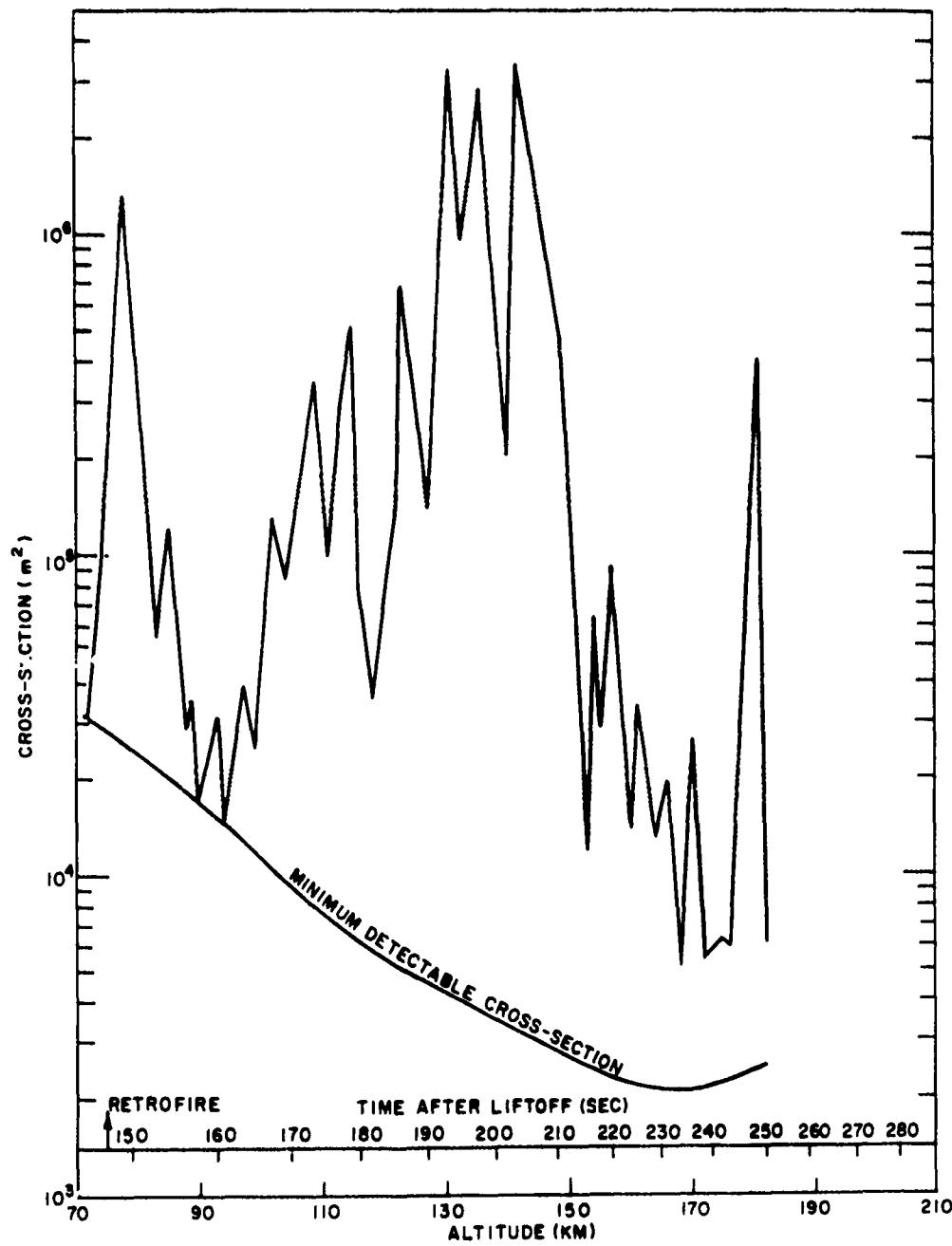


Figure 10. Signature cross section, SATURN SA-5,
San Salvador receiving Brunswick, Georgia.

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1.3×10^6 square meters immediately after ignition of the retro-rockets ($T_0 + 149$ seconds), and then the cross section dropped to the level of the pre-event E_s -coupling (the minimum detectable cross section at this relative range) 10 seconds later. The target cross section begins to increase as the S-IV stage attains an altitude greater than 100 km; the cross section reaches its maximum value of about 3×10^6 square meters at $T_0 + 205$ seconds.

The target amplitude shows a significant increase in size at approximately $T_0 + 246$ seconds, similar to that observed on the Cape Kennedy-receiving-Brunswick path. San Salvador's reception at Brunswick transmissions exhibits a target size more than an order of magnitude larger than that observed on the Cape Kennedy-receiving-Brunswick path. This effect could possibly result because a substantial part of the Cape Kennedy-receiving-Brunswick transmission path passes through a region of flame attenuation behind the missile.

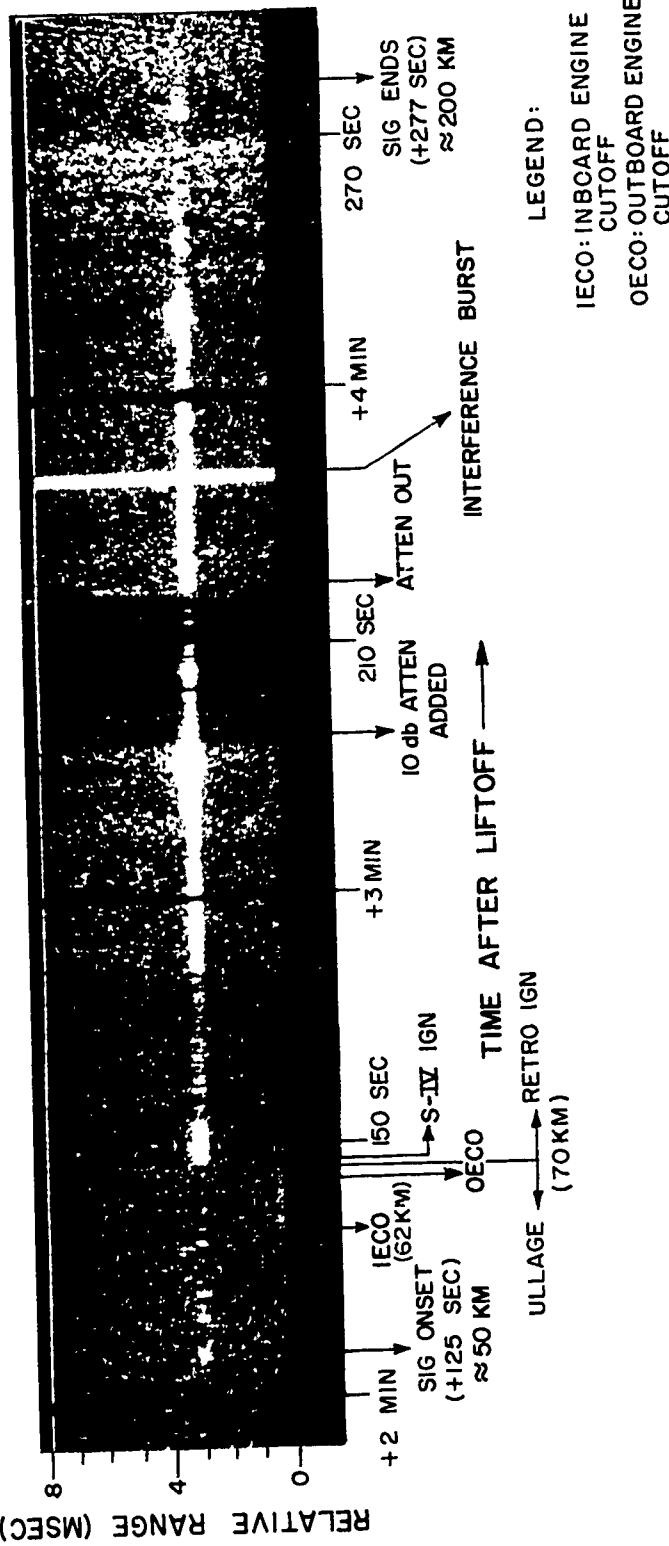
2.1.2.3. Brunswick Receiving San Salvador

Brunswick's reception of San Salvador transmissions produced the signature shown in Figure 11. This record is similar to the San Salvador-receiving-Brunswick record of Figure 5, showing essentially the same amplitude-time history for the missile signature. The radar cross section time history of this signature is given in Figure 12. The general magnitude of this cross section is equivalent to that of Figure 10 although there are second-to-second differences in the signature fading behavior. The increased size of the radar target created by activation of the retro-rockets, as compared to the earlier S-I stage flame target, is difficult to determine with precision for the records of Figures 9 and 11 because of the intensity of direct-coupling signals.

The radar receiver used for recording San Salvador transmissions at Brunswick was coherent, and, thus, this receiver could provide pulse-doppler information for the signatures obtained. The doppler-frequency

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Figure 11. AMR test 0169, SATURN SA-5, Brunswick, Georgia receiving San Salvador, operating frequency - 22.8 Mc/s.

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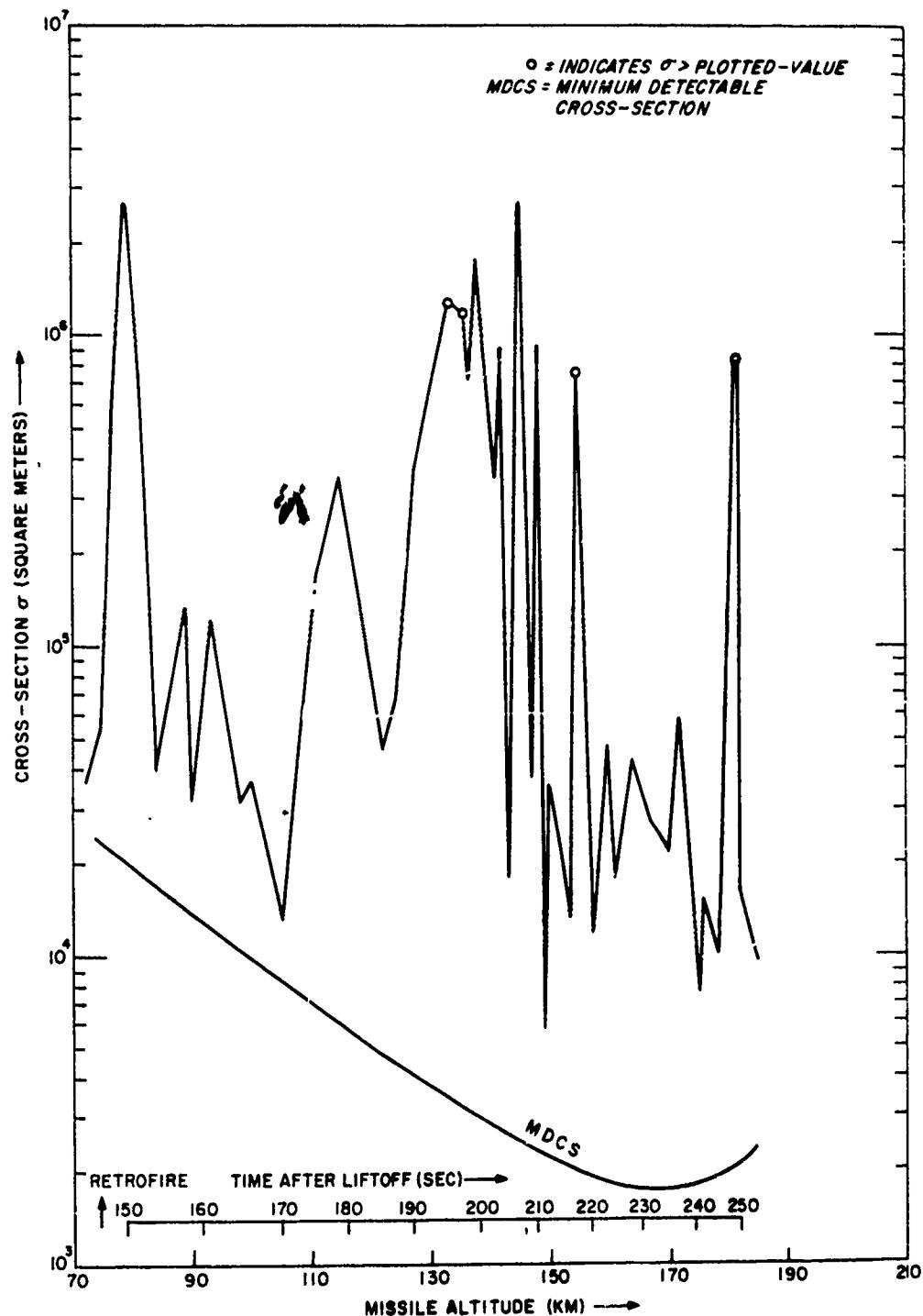


Figure 12. Signature cross section, SATURN SA-5, Brunswick, Georgia receiving San Salvador.

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readout provides a display covering a range from 0 to 85 cycles per second (c/s). Since the pulse repetition frequency was 100 c/s, frequencies higher than 50 c/s are ambiguously folded into the 0- to 50-c/s range.

Figure 13 presents the doppler history for the signature obtained on the Brunswick-receiving-San Salvador path. By using postflight information for the S-IV trajectory and a ballistic flight approximation for the S-I trajectory, doppler frequencies were calculated for the two stages, and these frequencies are presented in Figure 14. Also plotted on Figure 14 are the observed doppler spectral "lines" shown in Figure 13.

The doppler spectral "lines" of Figure 13 are somewhat intermittent and exhibit substantial spectral spreading of the discrete-doppler lines. The target echoes produce a noise-like spectrum over practically the entire doppler-filter passband (0- to 85 c/s) during the 180- to 195-second and 215- to 240-second time periods. The retro-rocket signature is characterized by a low frequency spectrum which is spread from 9 to 10 c/s.

The observed and calculated doppler frequencies agree closely for the 150- to 180-second interval, but the observed doppler frequencies depart significantly from predicated doppler frequencies at the end of the "doppler noise" period ($T_o + 195$ seconds). During the interval from $T_o + 190$ to $T_o + 210$ seconds, the observed change of doppler frequency does not seem to be related to the doppler frequencies calculated either for the S-I or for the S-IV stage, but later the change does approximate that predicted for the S-I stage from $T_o + 240$ to 250 seconds, when a discrete-doppler spectral line is again obtained.

It appears, therefore, that the observed target was not simply caused by the flame of the S-IV stage, although an accurate description of the target behavior is not possible when only the Brunswick-receiving-San Salvador data are used.

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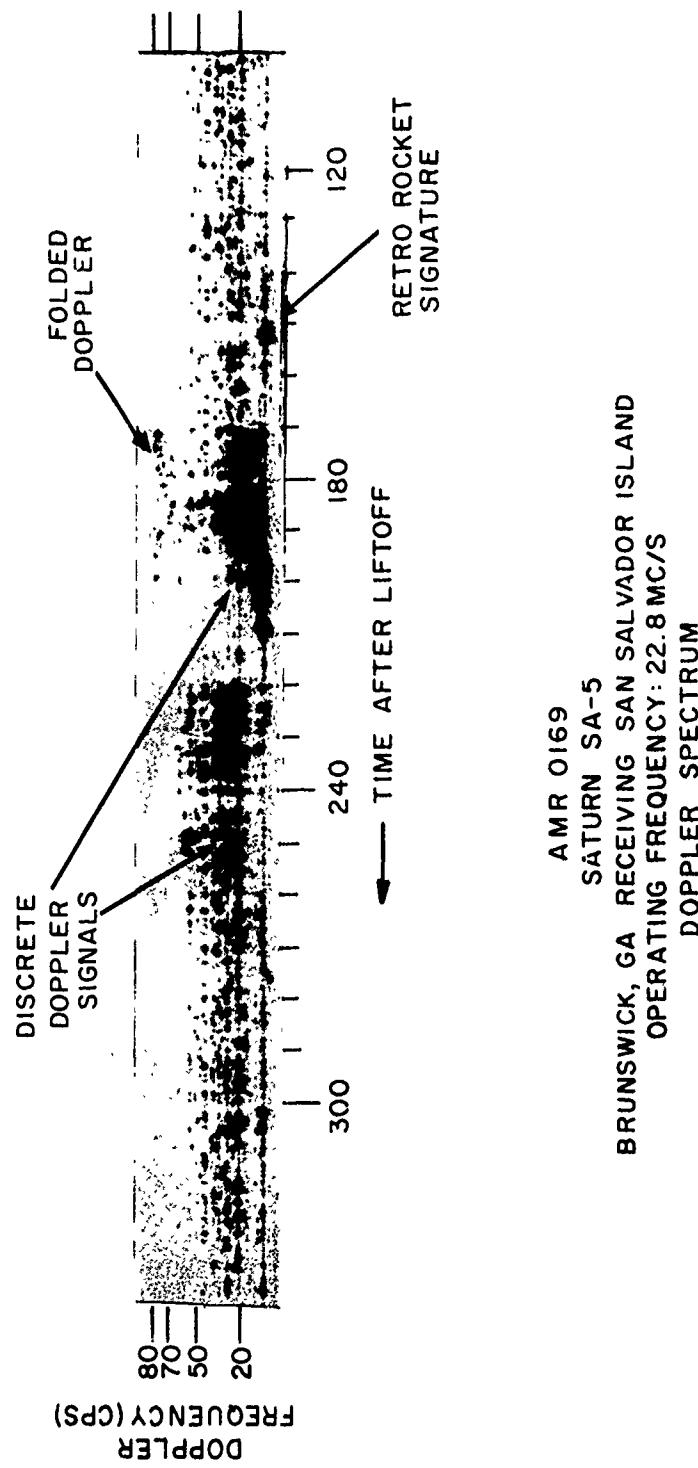


Figure 13. AMR test 0169, SATURN SA-5, Brunswick, Georgia receiving San Salvador, operating frequency - 22.8 Mc/s.

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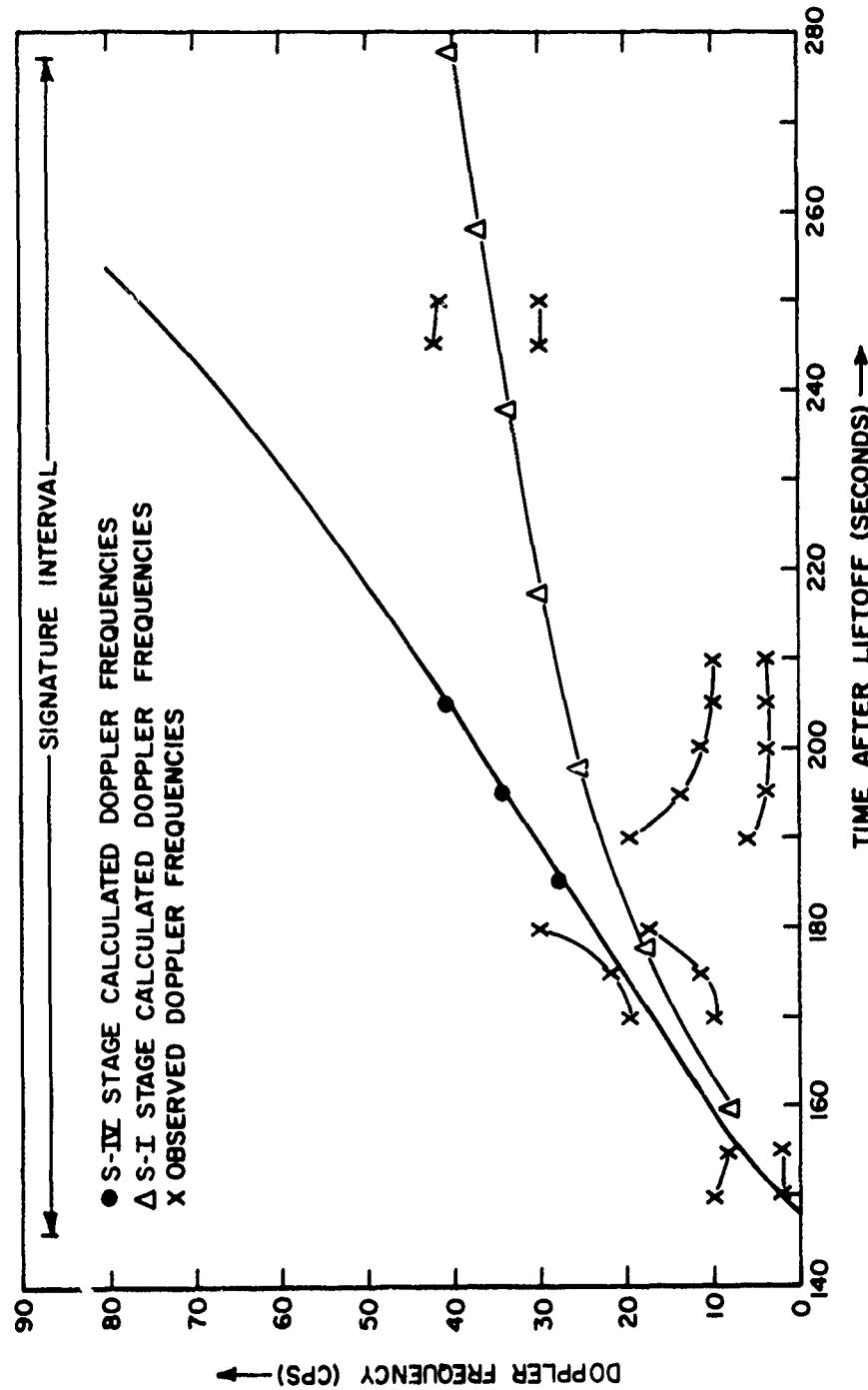


Figure 14. Comparison of calculated and observed doppler-spectrum lines, SATURN SA-5 stages S-I and S-IV, Brunswick, Georgia receiving San Salvador.

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2.1.2.4. Cape Kennedy Receiving San Salvador

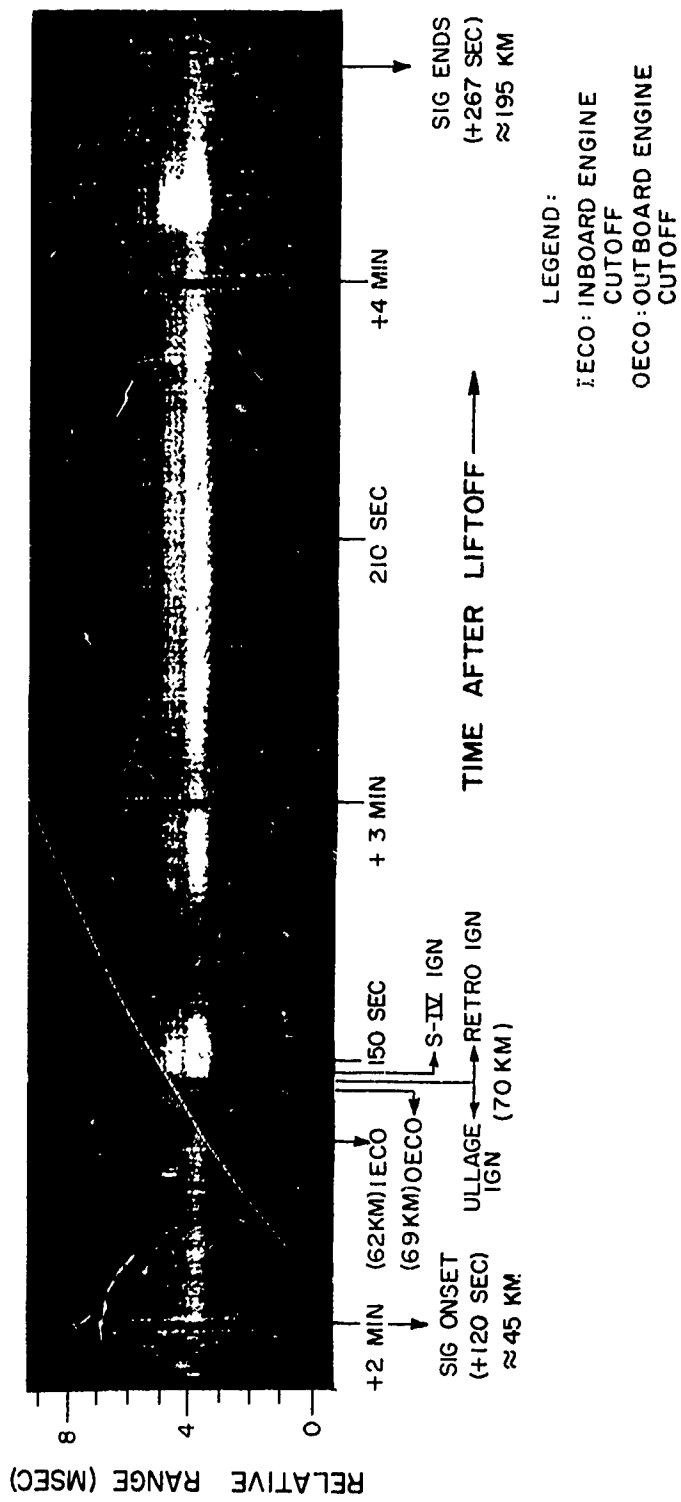
Cape Kennedy's reception of the San Salvador transmissions provides an interesting comparison with quasi-tail-on (Brunswick transmitter) versus quasi-head-on (San Salvador transmitter) illumination of the missile target as measured at Cape Kennedy. Cape Kennedy measurements of San Salvador signals for the SA-5 test produced the range versus time signature presented in Figure 15. A large target produced by the retro-rockets was observed from $T_0 + 148$ seconds to $T_0 + 155$ seconds; no further signature was obtained until $T_0 + 168$ seconds. A strong, specular signature occurred from $T_0 + 168$ seconds to $T_0 + 267$ seconds during the burning of the S-IV stage.

The signatures observed during the S-IV propulsion interval were much stronger on the paths with scatter angles greater than 90 degrees (i. e., Cape Kennedy receiving San Salvador), as opposed to a path with scatter angles less than 90 degrees (i. e., Cape Kennedy receiving Brunswick). Because of a calibration equipment malfunction for Cape Kennedy-receiving-San Salvador measurements, it was not possible to obtain accurate amplitude (i. e., cross section) information for these data.

The pulse-doppler spectrum for Cape Kennedy's reception of the San Salvador transmissions is presented in Figure 16. The retro-rocket signature is observed to have a doppler spectrum of 0 to 12 c/s, with a significant decrease in background noise-doppler intensities. After the retro-rocket signature, the doppler record shows an increase in background noise doppler; at $T_0 + 165$ seconds, a signature spectrum spread of about 30 c/s is observed. At $T_0 + 245$ seconds, a spread spectrum signature is again visible. The calculated bare-body doppler frequencies, using the Cape Kennedy-to-San Salvador path for both the S-I and S-IV stages, are presented in Figure 17. The signature spectrum observed at $T_0 + 245$ seconds is of the order of the doppler expected

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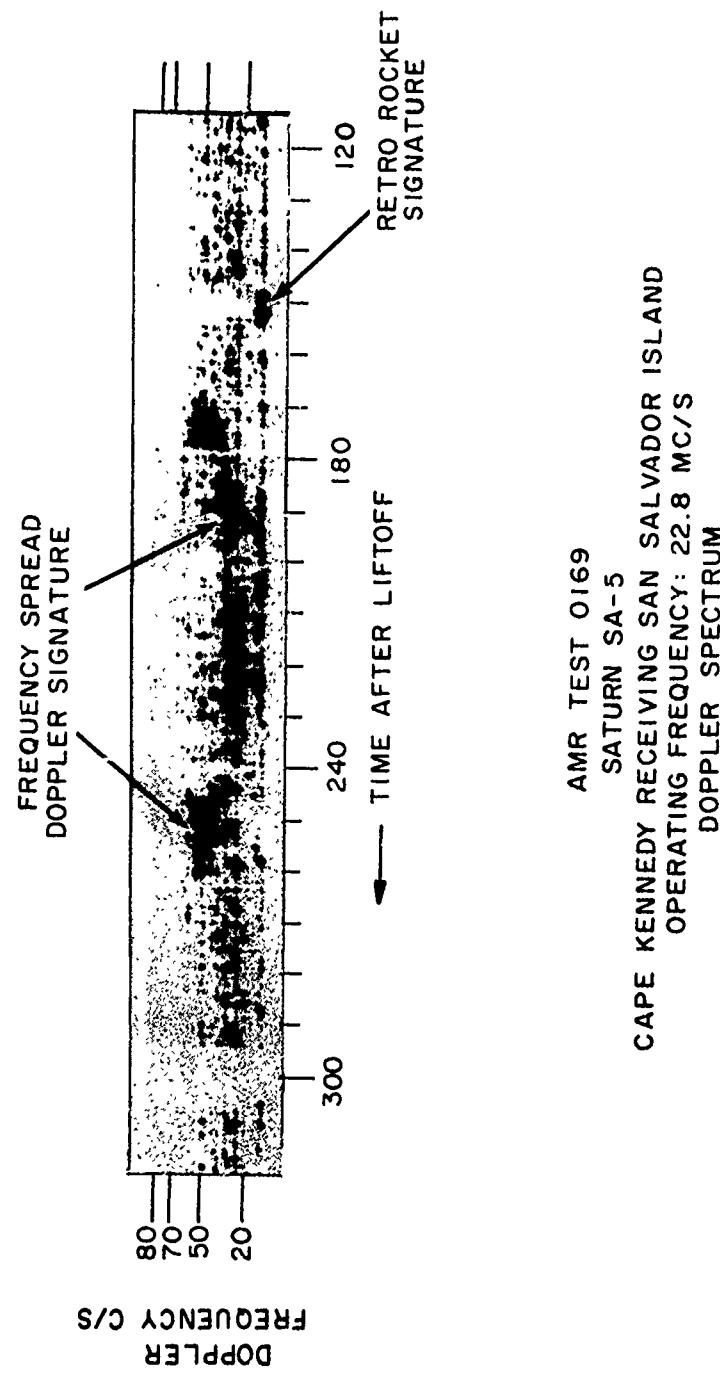
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Figure 15. AMR test 0169, SATURN SA-5, Cape Kennedy receiving San Salvador, operating frequency - 22.8 Mc/s.

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Figure 16. AMR test 0169, SATURN SA-5, Cape Kennedy receiving San Salvador, operating frequency - 22.8 Mc/s.

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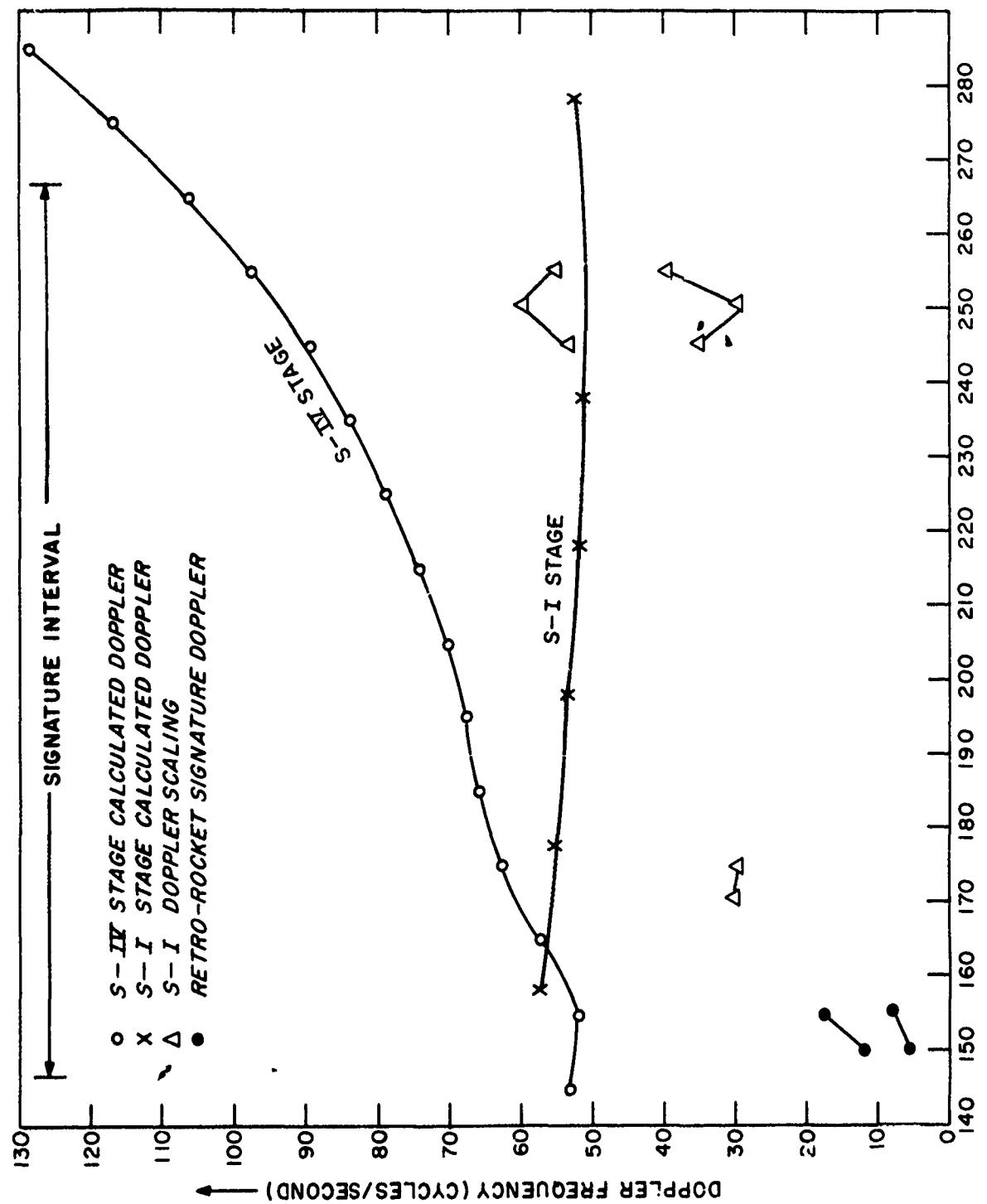


Figure 17. Comparison of calculated and observed doppler-spectrum lines. SATURN SA-5, stages S-1 and S-IV, Cape Kennedy receiving San Salvador.

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for the ballistic S-I stage. Again, no doppler signature was evident which correlated with that expected for the S-IV flame signature.

It would appear, therefore, that the enhancement of returns in the $T_0 + 240$ -second to $T_0 + 260$ -second interval may be associated with out-gassing of the S-I stage since both coherent measurements indicate a doppler spectrum appropriate to that calculated for a ballistic S-I stage trajectory.

2.1.2.5. Brunswick Monostatic

The Brunswick, Georgia monostatic radar operations produced a signature at the time of retro-rocket ignition (Figure 18). The signature appears at $T_0 + 148$ seconds and ends at $T_0 + 154$ seconds, its duration is approximately 4 seconds longer than the interval of high absorption for the VHF telemetry signals. This signature exhibits a cross section of approximately 4.8×10^6 square meters (Figure 19), which is about the same order of magnitude obtained for the San Salvador receiving Brunswick, Brunswick receiving San Salvador, and Cape Kennedy receiving San Salvador measurements. The lack of a discrete flame signature for the time history of the powered S-IV stage ($T_0 + 160$ to 240 seconds) strongly suggests that the S-IV flame target cross section was much smaller than that created by the firing of retro-rockets or by the outgassing S-I stage.

2.2. THE SA-6 FLIGHT

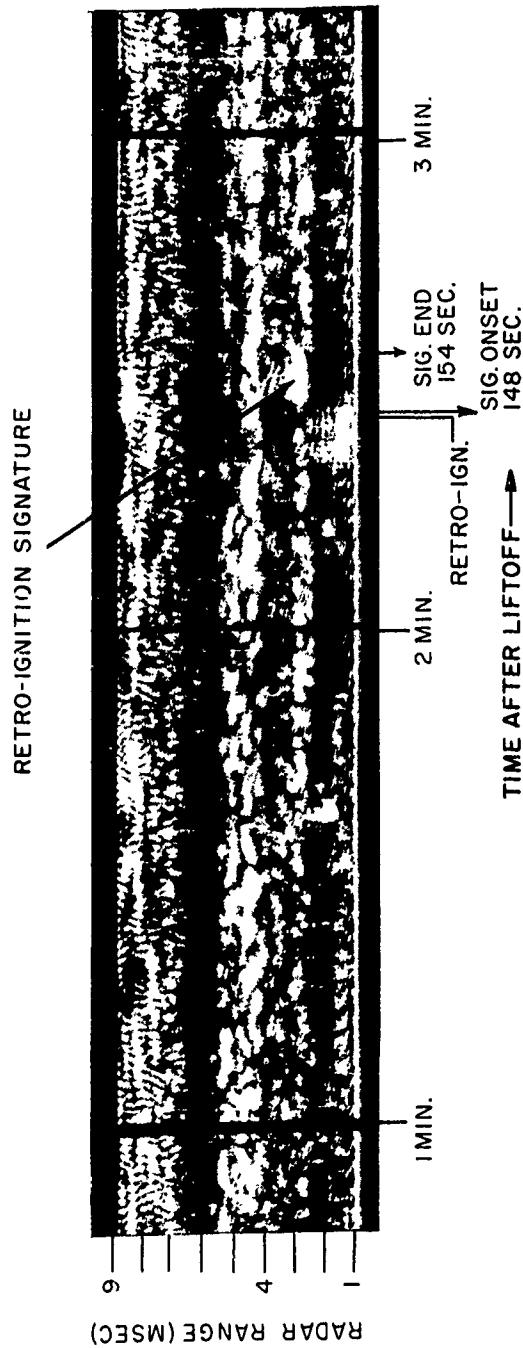
The SATURN SA-6 test vehicle was launched at 1707 GMT on 28 May 1964, at a 107° T azimuth from Cape Kennedy, Florida. The launch was successful, and the flight trajectory and staging times were generally similar to the SA-5 test.

2.2.1. VHF Telemetry from the SA-6 Vehicle

The amplitude of VHF telemetry signals from the SA-6 vehicle indicated attenuation phenomena similar to those of the SA-5 test. On

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Figure 18. AMR test 0169, SATURN SA-5 signature, lift-off -
1625:01Z, Brunswick, Georgia monostatic radar,
29 January 1964.

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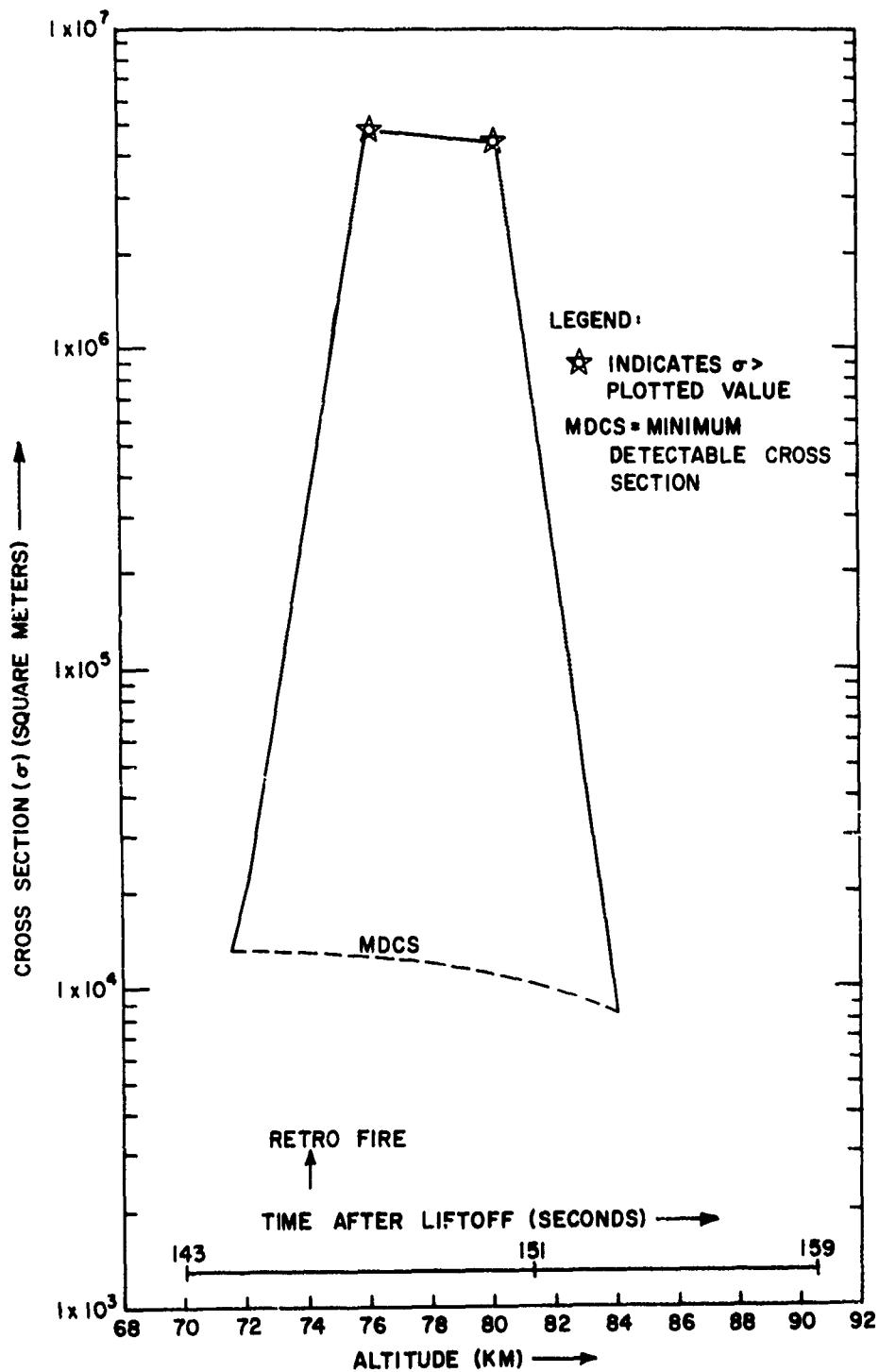


Figure 19. Cross section of the Brunswick, Georgia monostatic retro-rocket signature, SATURN SA-5.

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most of the telemetry links, the measured attenuation was less severe than for the SA-5 test. Retro-rocket ignition again produced a sharp reduction in signal strength to receiver detection threshold at the Cape monitoring site, as indicated by Figure 20. (SA-6 telemetry was producing relatively low signal levels prior to the time of retro-rocket ignition, thus, the measured attenuation appears to be smaller than for SA-5.) The onset of absorption at retro-rocket ignition was more gradual, and recovery was slower for the SA-6 test than for the SA-5 test. Recovery of the Cape Kennedy-telemetry-link signals to pre-retro-ignition levels took from 4 to 6 seconds, as may be noted in Figure 20.

2.2.2. Signatures Observed with HF Polystatic Direct-Look Radars

The signatures of the SA-6 tests, as observed by HF operations, were badly obscured by radio interference on the Cape Kennedy-receiving-Brunswick path and by direct coupling signals on the San Salvador-receiving-Brunswick path, as well as its reciprocal path direction. Nevertheless, the signature features observed were remarkably similar to those for the SA-5 test.

The Cape Kennedy-receiving-San Salvador signature for the SA-6 test is shown in Figure 21. After the retro-rockets ignited, a strong and discrete signature was observed from $T_0 + 150$ seconds to $T_0 + 156$ seconds, after which the amplitude of returns significantly decreased. The duration of these strong returns is the same as the time interval of measured VHF telemetry attenuation for the instrument unit (IU) transmissions (Figure 20). At $T_0 + 175$ seconds, when the missile reaches 97 km altitude, the amplitude of discrete HF target echoes again increases, and the signature remains visible until $T_0 + 378$ seconds (not shown in Figure 21).

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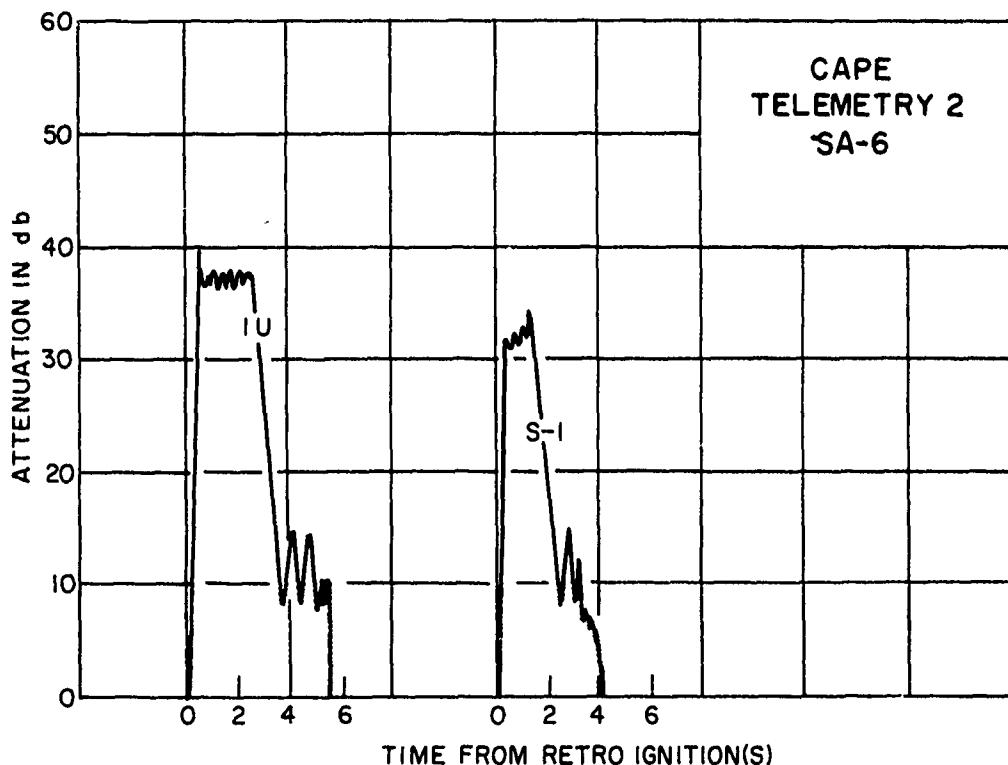


Figure 20. Telemetry signal attenuation due to retro-rockets.

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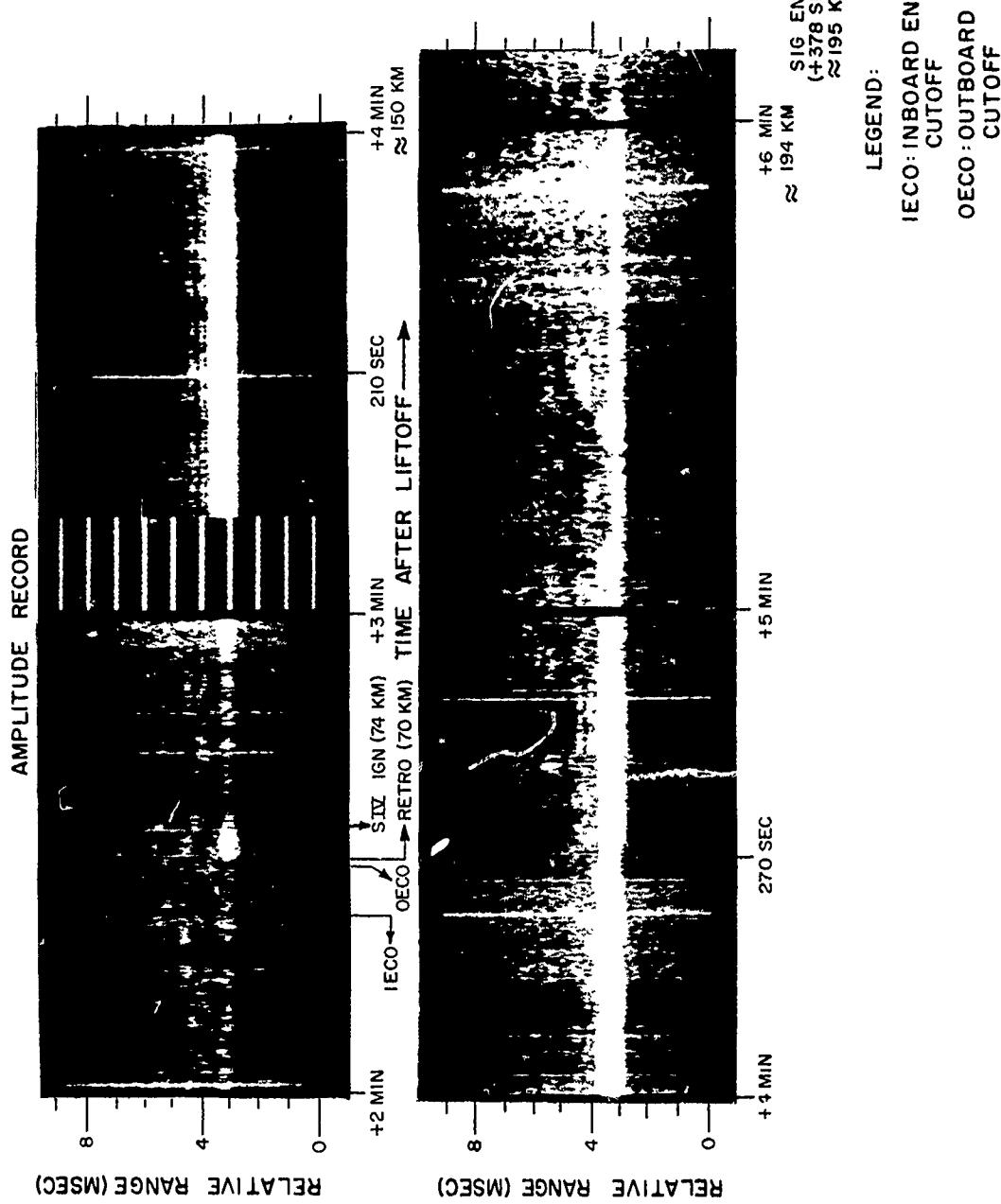


Figure 21. AMR test 2769, SATURN SA-6, Cape Kennedy receiving San Salvador, operating frequency - 17.7 Mc/s.

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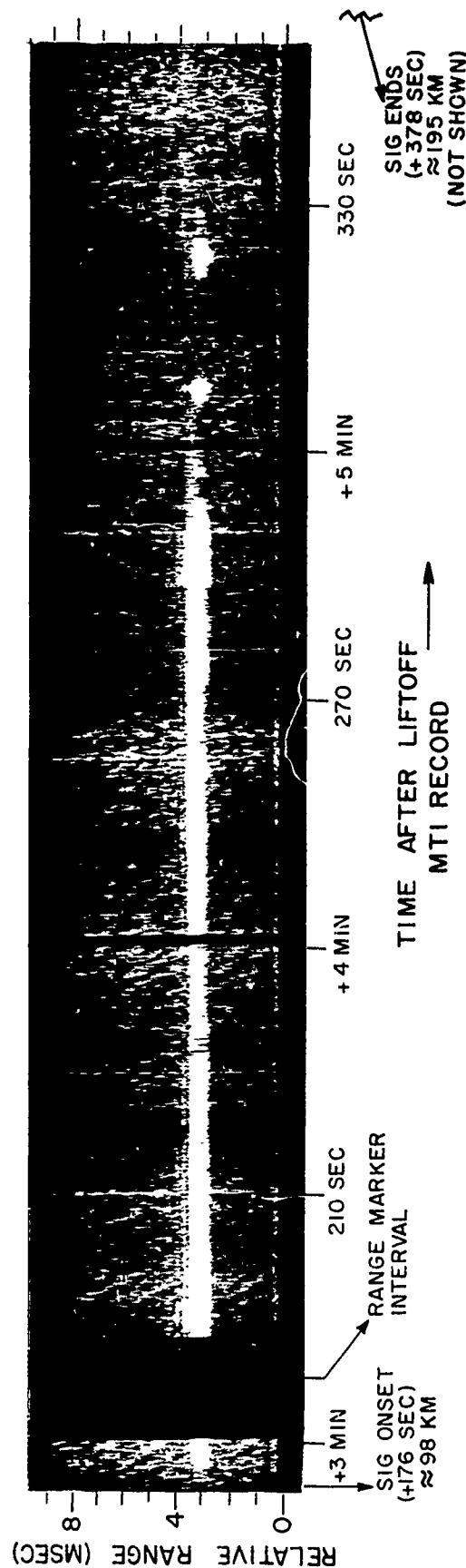
The signature in the interval from $T_o + 175$ seconds to $T_o + 364$ seconds again appears to be the result of out-gassing from the S-I stage. The powered S-IV stage signature is shown more clearly in Figure 22 (the result of MTI processing of the signals shown in Figure 21).

At $T_o + 294$ seconds, the discrete echoes are observed to occur at two slightly separated ranges, and continue to form two distinct signatures through $T_o + 330$ seconds. To substantiate that these two signatures were from the S-I and S-IV stages, a calculation was made of relative range separation for the two stages on the Cape Kennedy-receiving-San Salvador path, assuming a ballistic projectile trajectory for the S-I stage. Although the S-I stage did not follow a truly ballistic course after main engine cutoff, because of out-gassing effects and previous retro-rocket deceleration, this assumption should provide a rough first approximation to the relative positions of the two separate targets in the absence of post-burn S-I trajectory data. The result of this calculation yields a path-range separation of 80 km, or approximately 0.27 millisecond (time delay), for these targets at $T_o + 320$ seconds. This difference in path-range is consistent with the observed target returns (Figure 22) which show a path range difference of approximately 0.3 millisecond.

The pulse-doppler spectrum of SA-6 for the Cape Kennedy-receiving-San Salvador signature is presented in Figure 23. There are, clearly, two doppler signatures observed beginning at $T_o + 195$ seconds when a low frequency-doppler line appears below the previous discrete doppler returns at 30 to 40 c/s. The doppler signature first appears at

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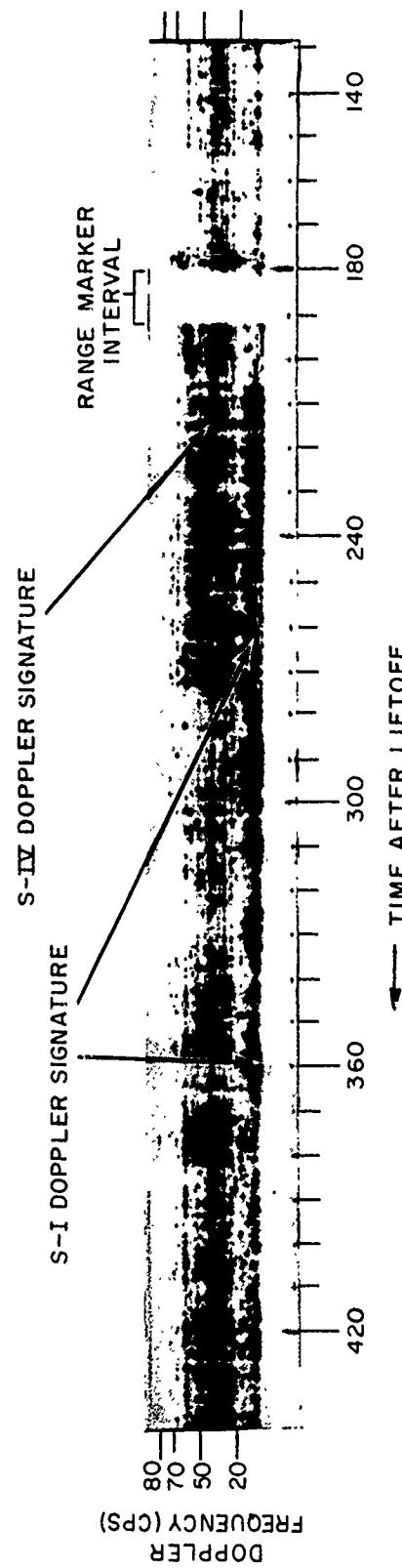
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Figure 22. AMR test 2769, SATURN SA-6, MTI record, Cape Kennedy receiving San Salvador, operating frequency - 17.7 Mc/s.

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AMR TEST 2769

SATURN SA-6

CAPE KENNEDY RECEIVING SAN SALVADOR

OPERATING FREQUENCY: 17.7 MC/S

DOPPLER SPECTRUM

Figure 23. AMR test 2769, SATURN SA-6, doppler spectrum, Cape Kennedy receiving San Salvador, operating frequency - 17.7 Mc/s.

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T_0 + 175 seconds, however, a set of range markers was applied to the record at T_0 + 181 seconds, which created a 10-second break in the data. The decreasing doppler-frequency component which separates from the increasing doppler-signature component is shown more clearly in Figure 24; this figure presents an expanded display of the 0- to 42-c/s spectrum. The retro-rocket signature is observed to produce a low-frequency doppler spectrum similar to that observed for the SA-5 test (Figure 23). Figure 25 presents a comparison of the calculated and observed doppler frequencies for the S-I and S-IV stages. A rather good agreement exists between the observed doppler trends and the calculated values for the two stages, even though the observed dopplers exhibit a significant amount of "spectral spreading". These data, thus, substantiate the hypothesis that echoes from the two stages could account for the complex signature characteristics observed during this test.

Since the Cape Kennedy-receiving-San Salvador signature character was complex (and derives from several distinctly different and inter-mixed target responses), no single or simple cross section calculation can describe this signature quantitatively.

The strong E_s -coupling signals, previously described for the Brunswick and San Salvador operations, make it impossible to distinguish the missile signatures from the interference; accordingly, records are not presented.

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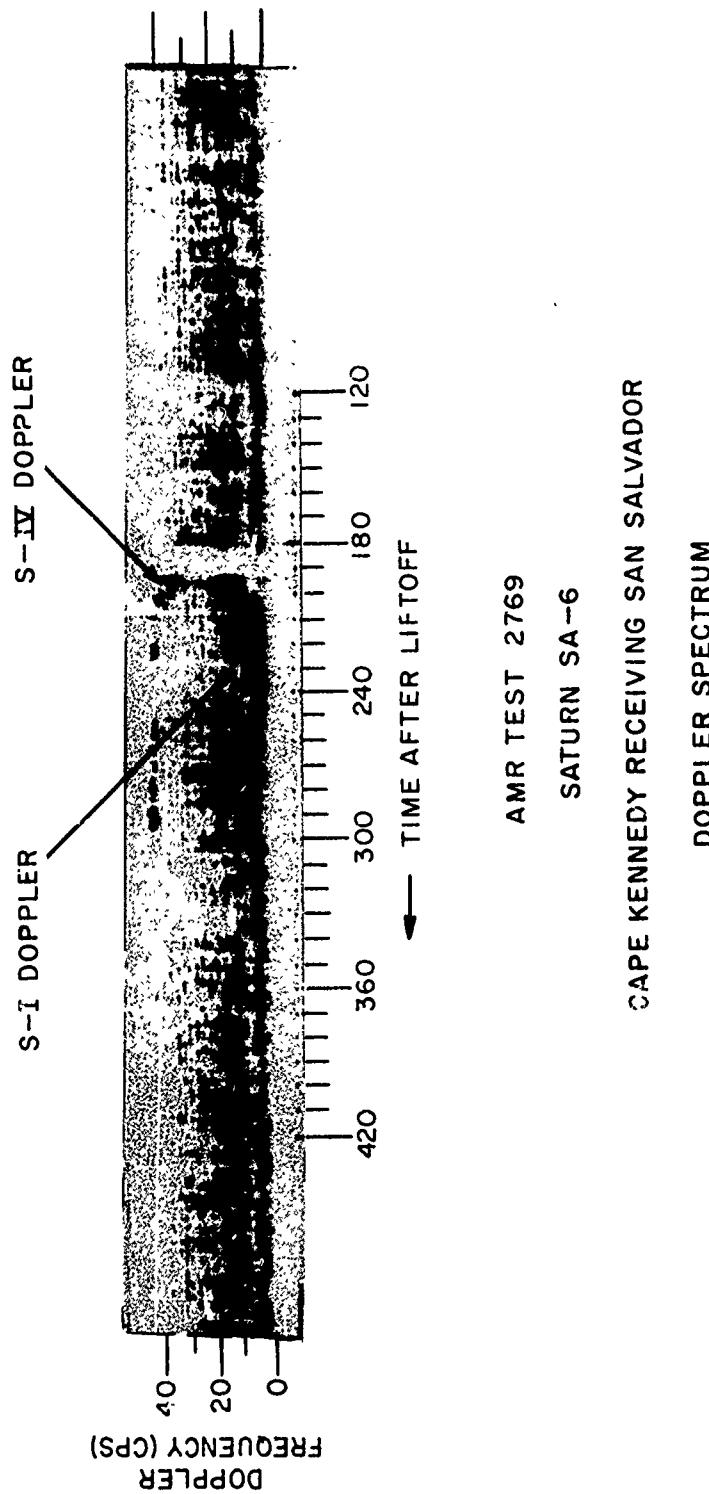


Figure 2. AMR test 2769, SATURN SA-6, doppler spectrum (continued), Cape Kennedy receiving San Salvador.

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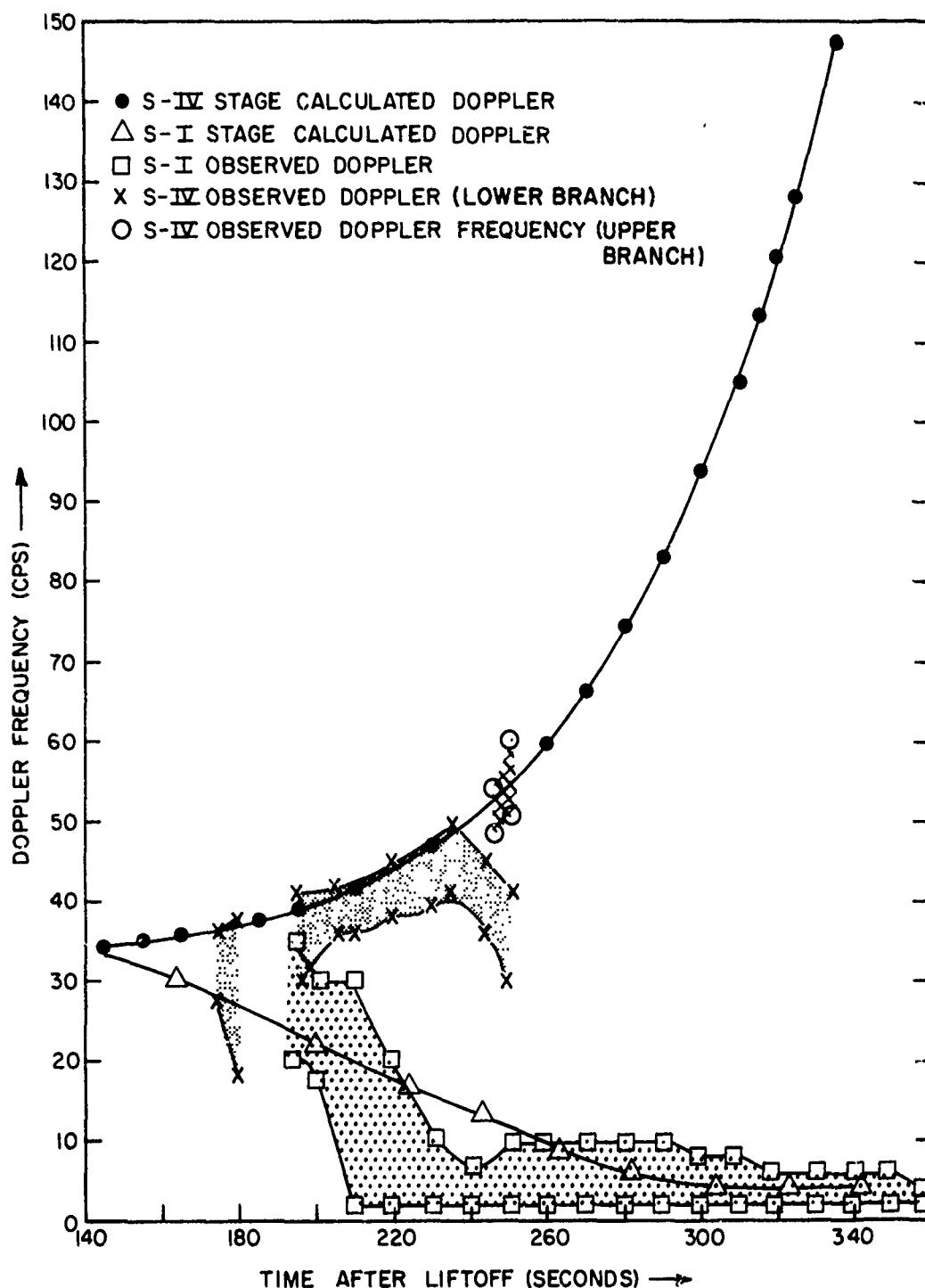


Figure 25. Comparison of calculated and observed doppler spectrum, SATURN SA-6, stages S-I and S-IV, Cape Kennedy receiving San Salvador.

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3. FLAME-ASSOCIATED VHF AND HF PHENOMENA

The modulation of the VHF telemetry signals by the rocket flame has been observed to produce both rapid and large amplitude scintillations, as well as a noisy spectral spreading of the monitored VHF telemetry data (Ref. 3). The maximum frequency spread, as reported by Ely and Hockenberger (Ref. 3, Figures 21 and 22), was approximately 1000 c/s from the carrier frequency for both liquid- and solid-fueled rocket motors. The noise modulation of the VHF telemetry is most pronounced when the vehicle is in the 30-km to 200-km altitude region. The noise modulation is reported most severe for the Cape Kennedy monitoring sites at tail-on aspects, and this modulation becomes gradually less for side and head-on viewing aspects which do not pass through the rocket flame.

On the basis of observed VHF telemetry flame effects, one might expect similar amplitude and spectral modulation of the energy reflected, at HF frequencies, from the ionized rocket plume at similar aspect angles. For HF pulse radar observations of rocket launches, rapid amplitude fluctuations would predominate, and discrete flame signatures would appear quite "noisy" even when the received signal is well above normal background noise. This has been true for flame signatures observed in the past by the Electro-Physics Laboratories, and statistical studies of these amplitude fluctuations have been made previously (Ref. 7). The pulse-doppler measurements presented in this report indicate substantial "spectrum spreading" for the particular targets observed. Although the complex target returns observed for the SA-5 and SA-6 tests would be expected to produce a number of discrete spectral lines, the "doppler spreading" of discrete signatures (e.g., the S-IV doppler "line" shown in Figure 23) would seem to be associated with flame-induced modulation effects similar to those observed on VHF telemetry transmissions (Ref. 8). Asymmetric "frequency spreading" of missile flame signatures has been observed

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by most HF CW-doppler radar operations (Refs. 9 and 10) for targets above 100-km altitude, and the presence of both amplitude and phase-flame "noise" modulations appears to constitute a mechanism for generating this "spectrum spreading".

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4. CONCLUSIONS

The following conclusions are derived from the rocket launches described.

- (1) HF radar observations of the SA-5 and SA-6 vehicles produced target signatures of considerable complexity. Some features of these signatures would appear valuable in applications to over-the-horizon radars, while others would, if not recognized, provide serious degradation to system performance for some radar formats. A number of the particular signature characteristics should be recalled, and conclusions should be drawn as to their significance.
- (2) First, the dual-ranged echo traces observed, one from the true second-stage flame-target and another from the coasting (and outgassing) discarded first stage were resolved by the experimental radars when the first-stage outgassing signature no longer obscured the more desirable flame target. It is clear, however, that the first-stage signature, although it might characterize an interesting event in the launch sequence, its range-rate and derived doppler velocity read-out would provide a false indication of the desired target motion for a substantial interval of the signature.
- (3) The very small solid propellant retro-rockets of the SATURN S-1 stage produce a surprisingly large HF target response. The retro-fire signature, at about 70 km altitude was clearly 2 to 3 orders of magnitude larger than the high-thrust-level flame echoes observed at this and somewhat higher altitudes. Simultaneous VHF telemetry blackout and SHF radar signal degradation were observed, along with the brief, but large, HF radar echo enhancement caused by the retro-fire event. This indicates that unusually large electron

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densities or density gradients were present at this time. The retro-fire signature, therefore, denotes an event of some interest in the overall sequence of launch phenomena, but despite the large cross section of such a target, its short persistence, spectral dispersion, and non-correlated amplitude variations would prove of little value for discerning the proper target motion and trajectory.

(4) The observed doppler-frequency spreading and rapid amplitude scintillation for HF radar signals reflected from the powered targets, for both the transient and more persistent signature features, closely resemble the noise-like phase and amplitude modulations appearing on VHF telemetry signals transmitted through the exhaust regions. These flame and ambient plasma effects would seriously degrade the resolution of discrete target motion by the use of a pulse-doppler radar format. In particular, a pulse-doppler, over-the-horizon radar system which must use a low pulse repetition frequency (PRF) (to achieve a sufficiently large, unambiguous range) would perform poorly against these target characteristics because the PRF would be a small fraction of either the target-motion doppler or the plasma-dispersed spectrum, or both.

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1. ORIGINATING ACTIVITY (Corporate author) ITT Electro-Physics Laboratories, Inc. Hyattsville, Maryland		2a. REPORT SECURITY CLASSIFICATION SECRET 2b. GROUP GP-3
3. REPORT TITLE RADAR AND TELEMETRY OBSERVATIONS FOR TWO SATURN LAUNCH VEHICLES (U)		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Report No. 65 of the Chapel Bell Series		
5. AUTHOR(S) (Last name, first name, initial) Bowser, Carl A.		
6. REPORT DATE January 1966	7a. TOTAL NO. OF PAGES 64	7b. NO. OF REFS 10
8a. CONTRACT OR GRANT NO. 4204(00)	9a. ORIGINATOR'S REPORT NUMBER(S) Chapel Bell Report No. 65	
b. PROJECT NO. NR 088-024	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) NA	
c.		
d.		
10. AVAILABILITY/LIMITATION NOTICES All distribution of this report is controlled. Qualified DDC users shall request through the Office of Naval Research, Code 418.		
11. SUPPLEMENTARY NOTES NA	12. SPONSORING MILITARY ACTIVITY Code 418 Office of Naval Research Washington 25, D. C.	
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